



**SIMULATION ANALYSIS OF HIGH
VELOCITY MAINTENANCE FOR THE B-1B**

THESIS

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AFIT-OR-MS-ENS-10-08

**DEPARTMENT OF THE AIR FORCE
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THESIS

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Abstract

This thesis explores the impact that High Velocity Maintenance (HVM) will have on aircraft availability rates for the B-1B by examining the proposed changes to the field maintenance and supply processes for the two B-1B squadrons of the 28th Bombardment Wing located at Ellsworth AFB, SD. There is a significant restructuring of depot level maintenance planned with the implementation of HVM, and the impact that this will have on base-level operations is important to determine, for it will provide insight as to whether or not HVM will be a feasible program with a high probability of successfully improving B-1B aircraft availability rates.

To examine the impact of HVM at the base level, discrete-event simulation is used. Two simulation models are created in ARENA 12. The first model captures the current state of operations for the base maintenance and supply processes, while the second model captures the processes as they are planned with the implementation of HVM. Comparisons of the two models reveal that HVM does have the potential to significantly improve aircraft availability rates, but the improvements that must occur with aircraft failure rates and base stockage effectiveness for HVM to operate as planned may not be feasible.

*To the wonderful, gregarious, affable, and undoubtedly good-looking individual(s)
responsible for the evaluation of this thesis. Please be compassionate.*

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Since my space is limited, I will thank the rest of you in a format that I learned to utilize very effectively during my course of study at AFIT.

Thankee	Reason
GOR 10-M Class	Helping me get through the challenging GOR program
Roommates	Cleaning up after me
BCMA Crew	Turning me into a Brazilian Jiu-Jitsu practitioner and deforming my ears
Mr. Fryman/Mr. Nepo	Me like data
Parents/Family	Food, shelter, love and life
G. W. Leibniz	Discovering the calculus
Jaco P./Marcus M.	The dirty, greasy, funky bass lines
Taylor Swift	Reaching the age of consent so my crush on you is no longer criminal
AFPC	Sending me to Florida next
Genghis Khan	Founding and ruling the largest contiguous empire in history
Yuri Gagarin	First human in space
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Table of Contents

	Page
Abstract	iv
Dedication	v
Acknowledgments.....	vi
List of Figures	x
List of Tables	xii
I. Introduction	1
Background	1
Problem Statement	4
Problem Approach	5
Research Scope	6
Thesis Outline	7
II. Literature Review	8
Chapter Overview	8
History of the B-1	9
Air Force Smart Operations for the 21st Century	11
High Velocity Maintenance	16
Work in the field of Discrete-Event Simulation	23
Summary	29
III. Methodology	30
Chapter Overview	30
Summary of the 28th Bombardment Wing.....	30
Development of the Current State Conceptual Model.....	32
Modeling Assumptions and Limitations.....	39
Current State Model Description	42
B-1B Generation	42
Normal Operations.....	46
Scheduled Maintenance Inspections	48
Unscheduled Maintenance	52
Changes to Base Operations under HVM.....	55
HVM Model Description	57
Verification and Validation of the Simulation Models.....	59
Summary	61

	Page
IV. Analysis and Results	63
Chapter Overview	63
Simulation Run Setup	64
Metric Selection	65
Comparison of Current State Model to the Baseline HVM Model	66
Identification of HVM Impact Factors	68
Comparison of Current State Model to the Best Case HVM Model	77
Summary	78
V. Conclusions and Recommendations	80
Chapter Overview	80
Analysis Implications.....	80
Feasibility of the Best Case HVM Model.....	81
Future Research and Conclusions.....	83
Appendix A. Fitted Process Distributions used in the Simulation Models.....	84
Appendix B. Paired <i>t</i> -Test Comparison of the Current State Model to the Baseline HVM Model	94
Appendix C. Paired <i>t</i> -Test Comparison of the Current State Model to the Best Case HVM Model	97
Appendix D. HVM Model 3 ³ Generalized Factorial Design	100
Appendix E. Blue Dart.....	108
Appendix F. ENS Quad Chart	111
Bibliography	112
Vita	117

List of Figures

	Page
Figure 1. Structure of the 28th Bombardment Wing.....	31
Figure 2. Conceptual Flow of Current State Base Operations Model.....	37
Figure 3. Conceptual Flow of Supply Process Piece of Unscheduled Maintenance	38
Figure 4. Generation Portion of the Current State Model	43
Figure 5. Normal Operations Portion of the Current State Model	47
Figure 6. HSC Portion of the Current State Model	48
Figure 7. ISO Portion of the Current State Model	48
Figure 8. Avionics End-to-End Check Portion of the Current State Model.....	49
Figure 9. Initial Unscheduled Maintenance portion of the Current State Model.....	53
Figure 10. HSC/PDM Portion of the HVM Model	58
Figure 11. ANOVA Table for MC Rate Estimate Factorial Model	70
Figure 12. Contour plot depicting the impact of the maintenance improvement factor and base stockage effectiveness on MC rate estimates	71
Figure 13. ANOVA Table for the TNMCS Rate Factorial Model.....	72
Figure 14. Contour plot depicting the impact of the maintenance improvement factor and base stockage effectiveness on TNMCS rates	73
Figure 15. TNMCS rate interaction plot of the maintenance improvement factor and base stockage effectiveness	74
Figure 16. ANOVA Table for the Average Total Unscheduled Maintenance Days Factorial Model	75

Figure 17. Contour plot depicting the impact of the maintenance improvement factor and base stockage effectiveness on the average total unscheduled maintenance days	76
Figure 18. Distribution Summary for Isochronal Inspections	84
Figure 19. Distribution Summary for PDM	85
Figure 20. Distribution Summary for Time to next Aircraft Failure.....	86
Figure 21. Distribution Summary for Unscheduled Maintenance Times	87
Figure 22. Distribution Summary for DLA Supply Delay	88
Figure 23. Distribution Summary for AFMC Depot Supply Delay	89
Figure 24. Distribution Summary for Lateral Supply Delay	90
Figure 25. Distribution Summary for AMARG/Surplus Supply Delay	91
Figure 26. Distribution Summary for MRSP Kit Supply Delay	92
Figure 27. Distribution Summary for Aggregated Alternate Sources Supply Delay.....	93
Figure 28. Normal Probability Plot of the Studentized Residuals for the MC Rate Estimate Factorial Model	101
Figure 29. Studentized Residual Plots for the MC Rate Estimate Factorial Model	102
Figure 30. Normal Probability Plot of the Studentized Residuals for the TNMCS Rate Factorial Model.....	103
Figure 31. Studentized Residual Plots for the TNMCS Rate Factorial Model	104
Figure 32. Normal Probability Plot of the Studentized Residuals for the Average Total Unscheduled Maintenance Days Factorial Model	103
Figure 33. Studentized Residual Plots for the Average Total Unscheduled Maintenance Days Factorial Model	103

List of Tables

	Page
Table 1. Different Categories of Scheduled B-1B Maintenance	33
Table 2. Attributes assigned to each Aircraft during generation phase	46
Table 3. Fitted and Estimated distributions for Scheduled Maintenance Inspections in the Current State Model	51
Table 4. Supply Percentages and Delay Distributions calculated for Alternate Supply Sources	54
Table 5. B-1 Rates reported for November 2009	60
Table 6. Metric Comparison between the Current State Model and the Baseline HVM Model	67
Table 7. Summary of 3 ³ General Factorial Design	69
Table 8. Metric Comparison between the Current State Model and the Best Case HVM Model	77
Table 9. MC Rate Estimate Comparison of the Current State Model to the Baseline HVM Model	94
Table 10. TNMCS Rate Comparison of the Current State Model to the Baseline HVM Model	95
Table 11. Average Total Unscheduled Maintenance Days Comparison of the Current State Model to the Baseline HVM Model	96
Table 12. MC Rate Estimate Comparison of the Current State Model to the Best Case HVM Model	97
Table 13. TNMCS Rate Comparison of the Current State Model to the Best Case HVM Model	98
Table 14. Average Total Unscheduled Maintenance Days Comparison of the Current State Model to the Best Case HVM Model	99
Table 15. HVM Model 3 ³ General Factorial Design Table	100

Table 16. R^2 Values for the Factorial Models	107
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SIMULATION ANALYSIS OF HIGH VELOCITY MAINTENANCE FOR THE B-1B

I. Introduction

Background

As many of America's air assets are engaged in war efforts in Iraq and Afghanistan, a significant portion of active United States Air Force (USAF) aircraft are simultaneously battling another deadly enemy that threatens to cripple the entire fleet. This enemy has claimed seemingly indestructible landmarks, structures, and individuals throughout history. This enemy, though often stealthy, is very real; it is a necessary phenomenon of reality, and its destructive power is firmly rooted in the laws of thermodynamics. This enemy is age. During the Vietnam War, the average age of a US military aircraft was nine years. Currently, the average age of a US military aircraft is about 24 years, and planes such as the KC-135 Stratotanker are routinely flown by pilots roughly half as old as the aircraft itself (Montgomery, 2007).

As the fleet has continued to age, aircraft failures have increased, and more aircraft are unable to carry out their combat sorties. Today, largely due to failures, over 14 percent of USAF aircraft are grounded or operating under restricted flying conditions, which has caused overall combat readiness to decline by over 17 percent (Montgomery, 2007). Regarding the problem of growing aircraft age among operational planes in the Air Force, Lt. General David Deptula, USAF, made the following remarks:

These are geriatric airplanes...I have never seen anything like this...The question is what's going to go wrong next...We have never flown fighters this old. If you're driving a 28-year-old car, you can expect some problems. And 28-year-old cars don't go flying around at 700 miles per hour and pull 9 G's. (Montgomery, 2007:1)

In 2009, General Norton A. Schwartz, the Air Force Chief of Staff, and Michael B. Donley, the Secretary of the Air Force, gave testimony that the aging Air Force fleet requires "focused attention" (Scully, 2009). In addition to declining aircraft availability, the frequent failures of aging aircraft are plaguing maintenance crews throughout the Air Force. Since 1996, maintenance costs have increased by 38 percent, maintenance man-hours have increased by 50 percent compared to flight hours, and heavy repairs occurring at aircraft depots have increased by 41 percent (Montgomery, 2007). These numbers reveal evidence of a disturbing trend of decreasing aircraft availability and increasing maintenance costs that clearly cannot continue if the USAF is expected to maintain air and space superiority for the foreseeable future.

One airframe being hit particularly hard with aircraft availability issues is the Rockwell B-1B Lancer, a multi-role, long-range bomber capable of performing a variety of missions. The B-1B was created to replace the aging B-52 bomber, and brings many technological advances over the B-52, such as significantly lower radar cross-sections, larger payload capacity, increased speed, greater range, and advanced electronic countermeasures (USAF.com, 2009). However, the B-1B fleet has itself aged since it began service at Dyess AFB TX, in October 1986, and it is currently suffering significant maintenance issues that are preventing acceptable rates of aircraft availability (USAF.com, 2009). Over the past 18 months, the entire B-1B fleet is averaging a mission capable (MC) rate, which represents the percentage of time that an aircraft is

available to perform its intended flight duties, of just over 40 percent, which is quite far off from the USAF goal of 70 percent or greater (Malone, 2009).

In an attempt to improve B-1B availability rates, the USAF is currently in the process of implementing a new maintenance program for the B-1B that has been dubbed High Velocity Maintenance (HVM). The concept of HVM came about by examining the streamlined depot maintenance procedures of the US commercial sector and observing the relatively rapid turnaround times that airline companies are able to achieve with their aircraft that undergo heavy maintenance (Scully, 2009). The main goal of HVM is to reduce the amount of time that aircraft are spending at depot centers for Programmed Depot Maintenance (PDM), a thorough maintenance procedure that aircraft must undergo to remain airworthy. The plan is to bring each aircraft to the depot more frequently, but for much shorter periods of time. Instead of overhauling the entire airframe during every PDM action as is currently done, maintainers will service parts of the aircraft in a sequential fashion, allowing the entire overhaul to be performed over several depot visits (Scully, 2009).

In addition to reducing the total amount of time in PDM, HVM will also give depot mechanics more frequent contact with aircraft in the fleet, which will, in theory, improve aircraft failure rates. With more frequent depot visits, mechanics will have a better idea of the effects of heavy usage on the fleet and can prepare for common repairs that will be required, which will subsequently reduce the time that aircraft are down for failures (Scully, 2009). Although HVM explicitly outlines drastic changes to the way that PDM will be performed, the altered PDM flow introduced will undoubtedly have an

impact on base operations, since all B-1Bs will be due for depot visits more frequently, but for shorter periods of time.

Problem Statement

Although significant changes to PDM for the B-1B have been planned under HVM, the impact that the altered PDM flow will have on base operations has not been examined. The goal of this thesis is to determine the effects that HVM will have on the operations of the 28th Bombardment Wing, located at Ellsworth AFB, South Dakota. Ellsworth AFB is home to two squadrons of B-1B aircraft, the 34th and 37th Bomb Squadrons, which are sustained and supported through the various groups of the 28th Bomb Wing. Since HVM is still in its developmental stages for the B-1B, there are certain concepts and goals for which proper methodologies of implementation have not been outlined. As a result, some of the changes to base operations that will occur under HVM cannot yet be accounted for. However, since PDM will change the maintenance cycle of the B-1B, there will be definite changes to base maintenance and supply processes. The focus of this thesis will therefore be to capture the differences to the base maintenance and supply processes that will occur with the implementation of HVM and to assess whether or not these changes will have a significant impact on B-1B aircraft availability, an issue that is of prime concern to the USAF, and other metrics that will be outlined in more detail in subsequent chapters.

Problem Approach

Discrete-event simulation (DES) was chosen to analyze the effects of HVM. DES provides several advantages over analytical methods that are particularly applicable to the study at hand. Due to the complexity of the maintenance and supply processes that occur within the 28th Bomb Wing, finding analytical solutions to specific metrics would not be possible. DES provides an efficient way to capture the complexity of base operations. Also, since many changes that will occur to base operations under HVM are not well-defined, DES allows for easy changes to parameters within the simulation models, which can then be run to determine the effects the parameters have on the model outputs. Instead of having to solicit specific numbers for parameters within the HVM process from subject matter experts, reasonable range estimates will suffice, since parameters can be varied with ease.

Two simulation models were created in ARENA 12 to capture some of the differences that will occur under HVM. The first model captures a reasonable estimate of the current state of base maintenance and supply by explicitly simulating key pieces of these processes. The second model captures the base maintenance and supply processes as they are envisioned with the implementation of HVM. Common output metrics from both models can then be compared to determine whether or not there are significant improvements to aircraft availability under HVM. Aside from comparing a baseline case of HVM implementation, certain parameters were varied within the HVM model to test the sensitivity of the reported metrics to variations within a particular process. There are likely to be unforeseen events that will influence expected HVM performances and

timelines in unexpected ways, and varying parameters within the HVM model allows for realistic “what if?” scenarios to be examined.

Research Scope

Due to the complexity of the maintenance and supply processes of the 28th Bomb Wing, there was a significant amount of abstraction and simplification involved in creating the simulation models used for this analysis. Therefore, specific outputs from both models should not be taken as exact indicators of performance, since many real-world processes were either excluded or included in abstracted form. However, the differences between the outputs of the two models, while not exact, will provide useful insight as to the changes in aircraft availability that can be expected with the implementation of HVM.

Currently, HVM has not been fully implemented for any aircraft, and as a result, the parameters unique to the HVM model represent the best estimates of subject matter experts. As HVM progresses through its pilot stage and into full implementation, the parameters within the model can be refined to reflect real-world operations more accurately. Other changes brought about by HVM that are not yet realized can also be implemented into the model. As the effects of HVM become more well-known, the models used for this simulation study can be refined to include more detail. Important base operations that have been ignored can be included, which will provide a more realistic picture of the impact HVM will have on a wider variety of base operations.

This study was intended to be a first cut effort to explore and understand the high-level impacts that HVM will have on base maintenance and its ultimate effect on aircraft

availability. Future researchers will now have a foundation regarding the basic differences in base maintenance under both systems and can direct more detailed studies to focus on significant areas of impact.

Thesis Outline

The remainder of this thesis consists of four chapters. Chapter II provides a review of literature pertinent to HVM, and will give the reader background information that is crucial to understanding the reasons behind the HVM effort for the B-1B. Chapter III contains a detailed discussion of the development of the simulation models used for this study, from the conceptual development to the intricacies of the final models that were implemented in ARENA 12. Chapter IV covers the subsequent analysis methodology and results found in this study, and Chapter V presents reasonable conclusions and recommendations that logically follow from the analysis results.

II. Literature Review

Chapter Overview

Since HVM for the B-1B has not yet been implemented, its impact on the base supply chain and field maintenance operations has yet to be established. A search of scholarly literature revealed that a study of the predicted effects of HVM on field operations for the B-1B does not currently exist. The purpose of this literature review is to highlight concepts that are relevant to the implementation of HVM for the B-1B.

The literature review presents the concepts and initiatives that led to the HVM pilot program being developed for the B-1B. The history of the B-1 is discussed to establish its crucial role in the United States Air Force inventory. Next, parts of the scheduled inspection and maintenance requirements of the B-1B are summarized to examine the current maintenance process and to illustrate a need for improved efficiency. A discussion of Air Force Smart Operations for the 21st Century (AFSO21) and analogous process improvement initiatives within civilian companies follows to give the reader an understanding of the underlying concepts behind HVM.

Furthermore, since discrete-event simulation (DES) is used in this thesis to explore the effects of HVM, several articles are presented that are relevant to DES. In a variety of the articles, the authors use DES to study processes related to the base operations that HVM will impact, such as supply chain flow and aircraft maintenance. These relevant simulation models, along with their application and relevance to this research, are discussed. Examining the work of other researchers in the field of DES

aided significantly in the construction of the models used for study in this thesis. Other articles presented outline general methodologies for conducting successful DES studies that can be directly applied to the research at hand.

History of the B-1

The concept of the B-1 began in the 1960s, when a series of studies into developing a long-range, conventional multi-role bomber were conducted. The initial development contract of such a bomber was awarded to North American Rockwell in 1970, and on December 1974, the four initial B-1A aircraft made their first flight. During this time, the B-1A achieved several impressive performance feats, such as sustained low altitude flight at 200 ft, a top flight speed of Mach 2.2, and the successful launch of the AGM-69A short-range attack missile (SRAM), a nuclear weapon. (Sanford, 2009)

Although the B-1A program was terminated in 1977 due to cost growth and various budget constraints, flight testing continued at Edwards AFB, CA. On October 2, 1981, President Reagan announced that 100 B-1Bs would be acquired by the USAF as part of the Strategic Modernization program. Rockwell International acquired the contract, and the first production B-1B flew on October 18, 1984. There were several key differences between the B-1A and the B-1B. First, the speed requirement was reduced to Mach 1.25, which allowed for the inlet and over-wing fairing structure to be simplified, ultimately reducing production and maintenance costs of the aircraft. Furthermore, the gross take-off weight was increased from 395,000 lbs to 477,000 lbs, and the radar cross-section was reduced to a more appropriate level. Strategic Air Command received the first B-1B in June 1985, and production was increased to four

aircraft per month until the 100th B-1B was completed on January 20, 1988. (Sanford, 2009)

As the Cold War began to close in the 1990s, there was no longer a need for the nuclear mission of the B-1B; the aircraft has not stood a nuclear alert since 1997. In 1994, the B-1B underwent an Operational Readiness Assessment that began the Conventional Munitions Upgrade Program, which was a phased approach to convert the aircraft to a conventional weapons platform. Currently, three of the four phases of the program have been completed. The last phase, Block F, has been deferred indefinitely due to hardware developmental issues. (Sanford, 2009)

The B-1Bs were originally assigned to four Air Force Bases: Dyess AFB, TX; Ellsworth AFB, SD; Grand Forks AFB, ND; and McConnell AFB, KS. In 2001, some of the B-1Bs were retired, and the remaining 67 aircraft were divided between Dyess AFB, TX, and Ellsworth AFB, SD. (Sanford, 2009)

The B-1B has been valuable to the USAF in several key combat operations since its inception in the 1980s. The B-1B saw combat for the first time during Operation Desert Fox in December 1998, where the aircraft was used to destroy Republican Guard barracks behind Iraqi air defenses. The B-1B was also used in 1999 during Operation Allied Force in Kosovo. In most campaigns, although the B-1B did not fly a significant portion of the overall combat sorties, the plane was still responsible for delivering a substantial amount of payload on valuable targets. For example, during Operation Allied Force, six B-1s accounted for only 2 percent of the combat sorties, but dropped over 20 percent of the total tonnage throughout the entire campaign. Likewise, during Operation Iraqi Freedom, the aircraft only saw 1 percent of the total combat sorties, but dropped 22

percent of all guided weapons in the conflict. The B-1B currently holds 100 world records for speed, payload, and distance, and set 50 new records at the Edwards Air Force Base Air Show in 2003 (Sanford, 2009). Clearly, the B-1B is an extremely capable platform that will be valuable for many years to come.

Air Force Smart Operations for the 21st Century

In December 2006, the Air Force's continuous process improvement initiative was named Air Force Smart Operations for the 21st Century (AFSO21). AFSO21 was mandated by former Secretary of the Air Force Michael Wynne and former US Air Force Chief of Staff T. Michael Moseley in an effort to streamline several Air Force operations, making them more cost-efficient and effective (Matthews, 2009). The goal of AFSO21 was described by General Bruce Carlson as follows:

Under AFSO21 we're constantly examining all of our processes in an effort to eliminate waste and unnecessary work. By doing so, we will remain fresh and focused on what's important to mission accomplishment ... while continuously improving all we do. (Matthews, 2009:1)

AFSO21 has been built on continuous process improvement initiatives, such as Lean and Six Sigma. The term "Lean" refers to a managerial philosophy that originated in Japanese companies such as Toyota, Datsun, and Ricoh after the world economic crisis of the 1930s (Mukherjee, 2009). The concept of Lean is to create additional value by eliminating inefficiencies in a particular process (Durham, 2009). Tools like statistical process control (SPC), which was developed in America, and the just-in-time concept (JIT), which was pioneered in Japan, were used to implement the Lean concept and streamline inefficient manufacturing processes (Mukherjee, 2009).

In 1913, Henry Ford revolutionized the manufacturing process by integrating an entire production process that he called flow production. With flow production, Ford utilized consistently interchangeable parts, standard work and moving conveyance to create the first well-known moving assembly line. The fabrication steps were lined up in process sequences, with special-purpose machines and a go/no-go gauge system in place to assemble the components of the Model T within a few minutes. Machines became part specific, which was very different from the old American manufacturing system, which consisted of general-purpose machines grouped by process that had to be fitted to produce different required parts before final assembly. Although Ford made huge strides with regard to efficient process flow, the problem with the Model T was a lack of variety. Up through the end of production in 1926, each Model T was virtually identical. Other automakers were able to introduce variety, but their production systems remained inefficient; the design and fabrication steps regressed towards the old use of process areas that required much longer throughput times. (Lean Institute, 2009)

The second major revolution in manufacturing, which pioneered the lean principles that exist today, occurred with the Toyota Company in Japan. In the 1930s, Kiichiro Toyoda, Taiichi Ohno, and others at the company began to examine a way to provide both continuous, efficient process flow and a wide variety among products to satisfy customers. The Toyota Production System eliminated the lack of variety that was a problem in Ford's flow production by shifting the focus of the manufacturing engineer to the flow of the product through the entire process. Under the old system, the focus was on individual machines and trying to maximize each machine's utilization, which would not necessarily lead to an efficient manufacturing process. The new focus on the

product through the entire manufacturing process led to many innovations, such as sizing machines appropriately to the actual volume it would be required to produce, introducing machines that were capable of self-monitoring to ensure quality, lining the machines up by process sequence, and introducing a feedback mechanism that would allow for communication between the processes (each process step could notify the previous step of its current need for parts to prevent over- or underproduction). Although many of these innovations only have direct applications to the automotive industry, the concept of streamlining processes to make them simultaneously more efficient and effective could be applied broadly to many different business operations. (Lean Institute, 2009)

The concept of Lean thinking was later generalized by James P. Womack and Daniel T. Jones in the book *Lean Thinking* (2003). In this work, the authors summarize the concepts of Lean thinking into five steps:

- 1) Specify the value desired by the customer
- 2) Identify the value stream for each product providing that value and challenge all of the wasted steps that are necessary to provide it
- 3) Make the product flow continuously through the remaining value added steps
- 4) Introduce pull between all steps where continuous flow is possible
- 5) Manage toward perfection so that the number of steps and the amount of time and information needed to serve the customer continuously falls

These Lean principles are directly applicable from the point of view of civilian companies that are seeking to please customers. However, within the Air Force, Lean thinking instead focuses on the elimination of waste outlined in step 2. Several opportunities to eliminate waste are encountered during the base supply and maintenance process for the B-1B at Ellsworth AFB, SD and will be explored in later chapters.

Six Sigma is a business process methodology that aims for continuous process improvement. Six Sigma has very broad applications, and can be used to improve almost any process in a wide variety of industries. For example, Bank of America used the Six Sigma methodology to reduce the number of screens in its online loan application from ten to four (Pereira, 2009). Along with making the online loan application more user friendly, the online banking team developed safer desktop authentication techniques and a live text chat feature that allowed users to receive improved customer support.

The Six Sigma process is broken down into five steps (Pereira, 2009):

- 1) Design: Quality is defined and measured from the perspective of the customer. Problems are identified, goals for process improvement are created, and the project charter is formed.
- 2) Measure: Key process performance metrics are identified, and the performance of the current process is determined in great detail.
- 3) Analyze: Gaps between desired performance levels and actual performance levels are quantified. Data is used to develop and test theories as to why the disparity exists.
- 4) Improve: Options for improving the process are identified and tested.
- 5) Control: Monitoring procedures are established while the modified process begins to execute.

Six Sigma has had a significant positive impact on many different organizations throughout the world. Traditionally, Six Sigma has been applied to improve manufacturing processes, but many companies are beginning to apply Six Sigma in improving transactional and service processes, such as accounting, logistics, legal, and purchasing resources. In the article "Turning to Service Sectors", a process is defined as any combination of people, materials, equipment, methods, and information that perform

work (Snee, 2009:38). The authors argue that the principles of Six Sigma can be broadly applied to service applications. Several differences between manufacturing processes and service processes are noted. Non-manufacturing processes are typically not as well-defined or standardized. Bank of America's online loan application is an example of this, as many different customers would have differing opinions as to what would constitute an "improvement" in the online loan application. Manufacturing processes, on the other hand, are typically well-measured and have clearly defined improvement metrics, such as throughput times and costs of raw materials (Snee, 2009).

However, in spite of these differences, there are similarities between all types of processes that allow for Six Sigma to be successfully applied. Snee argues that all work, regardless of whether it is manufacturing-related or not, occurs through a system of interconnected processes. The key elements of any type of process can be identified, and from a high-level point of view, all chains of processes begin to look similar. Likewise, all processes involve inefficiencies and mistakes that can cause wasted efforts and even significant damage. In the manufacturing worlds, the additional work caused by mistakes/inefficiencies is called rework, and irreparably damaged goods are called waste (Snee, 2009). All processes involve some form of rework and waste, and Six Sigma allows the user to identify the root causes of rework to eliminate them.

The main goal of AFSO21, as stated by General Bruce Carlson, is to improve Air Force processes by eliminating waste and inefficiencies. The goal of eliminating unnecessary work for process improvement aligns perfectly with Lean thinking and the Six Sigma concept.

High Velocity Maintenance

As the fleet of the US Air Force grows older, it is becoming more difficult to maintain. In testimony given in early 2009, General Norton A. Schwartz, the Air Force Chief of Staff, and Michael B. Donley, the Secretary of the Air Force, have noted that the aging Air Force fleet will require “focused attention.” Over the past two years, a significant amount of F-15 and F-16 fighters, A-10 attack aircraft, C-130 and C-5 transports, KC-135 aerial tankers, and T-6 trainers have been grounded due to failures (Scully, 2009). Even relatively new aircraft that are still in production, such as the C-17, are experiencing failures much earlier than expected. A single problem – wing cracks – grounded 130 A-10s in 2008, which is over one-third of the entire fleet (Scully, 2009). The constant use of these aircraft in strenuous operations are compounding with the increasing age of the fleet to cause more failures. The average aircraft in the fleet is 24 years old, which is the highest average age in the history of the USAF. Worse yet, according to Air Force Materiel Command, the average age is expected to be 26.5 years by 2012 (Scully, 2009).

Generally, aircraft maintenance is accomplished by using a concept called block or progressive maintenance. There are many scheduled maintenance tasks that are involved in keeping an aircraft in safe flying condition, and these maintenance tasks are grouped into work packages known as blocks. The complete work package for an aircraft is referred to as a complete overhaul cycle. The groupings for maintenance checks are organized as follows (Hessburg, 2009):

1) *Daily Checks*

Daily checks are the lowest level (in terms of maintenance complexity) of scheduled checks. Actions such as pre- and post-flight inspections, fluid level checks, and emergency equipment checks are examples of daily checks. The purpose of a daily check is to conduct a relatively quick inspection of an aircraft to look for obvious damage or deterioration that needs repair. Daily checks are typically not demanding with regards to requirements for specific equipment, tools, or facilities. Daily checks are usually accomplished every 24 to 60 hours of accumulated flight time to ensure that the inspected aircraft remains airworthy (Hessburg, 2009).

2) *'A'/'B' Checks*

'A' Checks are the next highest level of scheduled maintenance. Normally, these checks are conducted at a designated maintenance station in the route structure. Some limited special tools, services, and test equipment are required, and the daily check items are completed during an 'A' check. Some examples of 'A' check actions are inspections of crew oxygen system pressure, emergency light checks, and parking brake checks.

'B' checks involve slightly more detailed inspections of aircraft components and systems, but typically do not require detailed disassembly or removal of components. For some contemporary maintenance programs, 'B' checks are not treated as a separate category of inspections; the maintenance actions are distributed between the 'A' and 'C' checks (Hessburg, 2009).

3) *Heavy checks – 'C'/'D' checks*

The next category of maintenance action groupings is called heavy checks. Unlike the lower categories, these checks are accomplished at the main maintenance base

of an airline company, where specialized tools, materials, hangar facilities, and mechanics are available. Although these checks occur much less frequently than the lower level maintenance checks that can be carried out at multiple service stations, heavy checks require the aircraft to be out of service for a significant amount of time, since the detailed inspections and replacements are quite time consuming (Hessburg, 2009).

For the B-1B, aircraft maintenance follows the block maintenance concept. B-1B aircraft maintenance is divided between base-level maintenance and depot maintenance. Currently, most maintenance actions required occur at the base level. These checks parallel the lighter ‘A’ and ‘B’ checks outlined above; the aircraft is able to be serviced at the base without being down for an extensive amount of time. The B-1B’s version of a “heavy” check is called programmed depot maintenance (PDM). To complete PDM, each B-1B must be sent to an AFMC depot, such as Tinker AFB, OK, where specialized tools and mechanics can conduct detailed inspections and repairs. PDM occurs approximately once every five years, and each aircraft is down for an extensive amount of time while at the depot.

One solution to the lack of aircraft availability due to failures is to decrease the time that aircraft are spending in depot maintenance. To accomplish this, the Air Force has launched a pilot maintenance program called High Velocity Maintenance (HVM). The intention of this program is to speed up the depot maintenance process to cut the amount of time that aircraft are spending undergoing overhaul and repairs, which in turn should increase aircraft availability (Scully, 2009).

The idea behind HVM is to bring aircraft to the depot more frequently, but for much shorter periods. Instead of overhauling the entire airframe, each depot maintenance

cycle would service parts of the aircraft in a sequential manner. Instead of going to the depot once every 5 or 6 years for a complete, lengthy overhaul, the depot will be seeing each aircraft about once every 18 months (Scully, 2009). By touching each aircraft more frequently, the same maintenance will be able to be accomplished with less down days, which will reduce an aircraft's out-of-service time. For example, there was a particular C-5B at Warner-Robins AFB that had not been to the depot in over six years. The planned time for the overhaul was around 50,000 hours, but due to unexpected problems, the plane actually required over 70,000 hours of work (Scully, 2009). Furthermore, the more frequent maintenance actions will give maintainers a better idea of how heavy usage is affecting each airframe, and predictive maintenance will be directed towards areas that are frequently failing. If the depot sees each plane more often and notices a pattern of failures common to a certain aircraft type, the depot will be able to preemptively stock parts to further speed up PDM. Another advantage of HVM is that it will allow workers on the flightline to focus on sortie generation instead of inspections and repair, since more inspections and phased maintenance will be handled at the depot (Scully, 2009).

The C-130 was the first aircraft to be assigned to undergo a pilot HVM program. Currently, the C-130 is spending an average of 164 days at Robins AFB, GA for PDM (Crenshaw, 2009). The process is lengthy because upon arrival, each C-130 must be inspected to determine what parts must be replaced. Once this is determined, each part must be acquired, which can take a significant amount of time. While the maintainers are waiting for the parts to arrive, the C-130 cannot be flown. The first C-130 to undergo the HVM process arrived at Robins AFB on 31 July 2009 (Crenshaw, 2009). Under the

HVM system, the condition of the C-130 aircraft was known in advance, which enabled the HVM team members to schedule workflow, develop kits for each maintenance procedure, establish requirements, and order all necessary parts and equipment (Drohan, 2009). This way, depot mechanics had everything they needed to perform their work, and did not have to leave the aircraft to search for the parts necessary to complete their job. The success of the pilot HVM program for the C-130 remains to be seen.

The B-1B, which has significant issues with aircraft availability, was also designated to undergo a pilot HVM program. In 2008, over half of the B-1B fleet was down due to some type of maintenance. The average amount of available B-1s was 28, with 36 down at any given time (Scully, 2009). In April 2009, senior officials from Air Force Materiel Command, Air Combat Command, and the Air Staff gave the B-1 HVM team based at Tinker AFB, OK approval to begin a B-1 HVM pilot program. The team is currently developing a schedule and working out all of the exact details as to how HVM will be applied to the B-1B, and plans to have partial implementation as early as October 2010 (Scully, 2009).

For the B-1B, unscheduled maintenance is currently causing the most delays (Scully, 2009). Although unscheduled maintenance is not usually handled by the depot unless some tasks are deferred, HVM will allow flightline mechanics to spend less time waiting for parts to arrive, since in theory the more frequent depot actions will decrease unscheduled failures.

Currently, the life-cycle maintenance program for the B-1B puts each aircraft at the depot for PDM approximately once every 5 years, and each aircraft undergoes PDM for an average of 182 days. There are also several inspections that are conducted at the

base level. Home station checks (HSCs) are scheduled every 150 calendar days and take an average of 5.6 days to complete. A minor isochronal inspection occurs every 900 calendar days, and takes an average of 15.6 days to complete. Major isochronal inspections are scheduled every 1800 calendar days, and take an average of 8.7 days to complete. During each inspection, the aircraft is down for the entire period, and sorties are not flown. Under the current method of operations, PDM is not in sync with the base isochronal inspections. Therefore, a significant amount of time is often wasted on redundant maintenance actions. (Malone, 2009)

The vision of HVM for the B-1B set by the HVM pilot team at Tinker AFB, OK is to increase aircraft availability using AFSSO21 tools to establish a standardized integrated sustainment plan that achieves mission requirements (Malone, 2009). For the B-1B, this vision will be accomplished by syncing field and depot maintenance to eliminate redundant maintenance actions, scheduling PDM for each aircraft once every 15 months as opposed to once every 5 years, increasing the burn rate for each aircraft, and by using a concept called kitting, which will provide depot mechanics with all of the tools, parts, and materials necessary to immediately begin maintenance repairs. All of these actions will act synergistically to decrease the amount of time that aircraft spends in maintenance, which will increase aircraft availability.

Synchronizing the field and depot maintenance actions will prevent maintainers (both field and depot) from having to reaccomplish maintenance actions that were recently completed on an aircraft. Increasing the maintenance burn rate and scheduling more frequent, but briefer PDM cycles will allow the maintainers at the depot to be much more efficient in conducting PDM. Since depot maintainers currently only see each B-

1B once every five years, the maintenance inspections for each aircraft are extremely lengthy, and the maintenance actions that each aircraft requires are much less standardized, since each aircraft has more time to experience different failures. Furthermore, since PDM will occur more frequently, base maintainers will have the option of deferring lengthy maintenance actions that do not immediately impact safety to the next PDM cycle, which will allow the aircraft to continue with daily sorties. Currently, this is often not a viable option, since the depot does not see each aircraft frequently enough.

As mentioned previously, unscheduled maintenance is currently causing the most problems with B-1B availability. Although unscheduled maintenance can never be fully planned for, HVM will, in theory, also reduce the amount of unscheduled maintenance actions that are required. Since each aircraft will be seen by maintainers more frequently, there are more chances to identify parts or systems that are expected to fail soon. The implementation of the kitting concept also expedites unscheduled maintenance, since maintainers will not waste time ordering and waiting for common parts that are necessary for aircraft maintenance.

Although HVM has not been fully mapped out or implemented for the B-1B, it shows a great deal of promise in being able to increase aircraft availability. HVM fits perfectly under the AFSO21 initiative, which seeks to make all Air Force processes more effective and efficient.

Work in the field of Discrete-Event Simulation

In the field of Operations Research, many tools are available to study the operation of a real-world system or process over time. Simulation, one of the many techniques that are available, is defined as the imitation of the operation of a real world-process or system over time (Law, 2007). The form of simulation modeling that is used to study the B-1B HVM process is called discrete-event simulation.

Simulation is a valuable technique that enables the study of the interactions of a complex system. However, simulation is not always an appropriate technique to use. Often times, creation of a simulation model and subsequent analysis is quite time-consuming. In *Discrete-Event System Simulation*, a commonly used textbook for introductory discrete-event simulation courses, the authors outline ten rules for evaluating when simulation is not appropriate. The first set of rules state that simulation should not be used if the problem at hand can be solved through common sense, analytic methods, or can be solved more easily through direct experimentation (Banks, 2010). The impact that HVM will have on base operations cannot be solved by analytic methods due to the complexity of the maintenance cycle and all of the random unscheduled maintenance that frequently occurs. Direct experimentation would not be a simpler or more cost-effective method of analysis, since the planning and infrastructure required to implement HVM requires significant monetary and human resources. The next set of rules deal with the feasibility of conducting a simulation study. A simulation study cannot be effectively conducted if resources, time, or data is lacking or if the system behavior is too complex to be defined (Banks, 2010). Fortunately, all of these barriers do not exist for the study at

hand. To capture the impact that HVM will have on base operations, simulation appears to be the most effective tool.

In an article presented at the 2008 Winter Simulation Conference, James T. Sawyer and David M. Brann outline a methodology for creating more effective simulation models by applying agile techniques to simulation. The authors describe a simulation study that was undertaken for a major US airline. The simulation study involved studying how pilots would respond to various hypothetical contracts and the effect that their decisions would have on daily flight operations. Although the simulation study was ultimately successful, the authors note that many projects that involve modeling complex processes often fail due to ill-defined project requirements and the large volume of model-building work that is required. The key to success in the airline simulation project, according to the authors, was their ability to focus on the process of model development before the actual modeling was attempted. A methodology for lean software development, which was outlined by Beck et al. (2001) in a document known as the *Agile Manifesto*, was applied to the process of creating a model. The key principles of the document included frequent software delivery to the customer for evaluation, welcoming late changes in requirements and project scope, and close, frequent cooperation between software developers and the customer (Sawyer, 2008). The authors applied this methodology to their simulation study by expecting and welcoming changes in project requirements. Furthermore, the authors used a “Milestones Approach” to divide the complicated simulation model into manageable pieces that could each be delivered to the customer for evaluation. In their study, four key concepts within the

Milestones approach were adequate planning of each milestone, frequent iterations, frequent testing, and frequent review (Sawyer, 2008).

Although the specific simulation study conducted by Sawyer and Brann is not directly applicable to the study of how HVM will impact base operations, the principles the authors used to successfully complete the simulation study are extremely valuable to any team that undertakes a complex simulation study that involves studying parameters and processes that are ill-defined or poorly understood. Three key concepts that stood out during the study were frequent collaboration with and feedback from the customer, dividing the modeling tasks into manageable milestones that can be completed, and the anticipation of changing project requirements and scope. Due to the complexity of base operations for the B-1B, all three of these concepts are applied to the simulation study at hand. Instead of attempting to model the entire process once the conceptual flow of base operations is understood, the different aspects of the base operations are modeled using the milestones approach. Frequent discussions with subject matter experts are also utilized to ensure that each aspect of the simulation model is created correctly.

A common theme among successful simulation studies is scaling the complexity of the model appropriately to answer the research questions at hand. In an article presented at the 2003 Winter Simulation Conference, Paul D. Faas and J. O. Miller created a discrete-event simulation model to study the impact that the Autonomic Logistics System (ALS) would have on daily F-16 sortie generation. Before the ALS concept was created, aircraft were flown until a failure occurred. Once the failure occurred, maintainers had to isolate the exact problem(s) and order appropriate parts before repairs could take place. Under ALS, a fully functional prognostics and health

management (PHM) system is used to actively scan each aircraft to determine if all systems are functioning properly. With PHM, maintainers could preemptively anticipate system failures and could defer maintenance actions that would not be crucial to daily sortie requirements. Along with PHM, which constantly monitors aircraft components for faults and deterioration, ALS also involves incorporating the Joint Distributed Information System (JDIS) into the logistics infrastructure. With JDIS, information on aircraft maintenance is made available to all appropriate logistics functions (Faas, 2003). To study the impact of ALS, a simulation model was created to model F-16 sortie generation operations. Instead of attempting to capture every process involved in F-16 sortie generation, the authors scoped the model appropriately to focus on the impact of ALS vs. current system procedures. Rather than attempting to model all of the systems on the F-16 that could fail, the authors focused only on the maintenance process for the AN/APG-68 radar. The entire supply system, instead of being modeled explicitly, was set up with simple counters and delays for each possible source of supply. Although many of the real-world processes were abstracted or simply ignored, valuable insight was still able to be gleaned from the simulation study; the model indicated that with ALS in place, aircraft availability would improve. (Faas, 2003)

In another simulation study conducted by Todd S. Bertulis and J. O. Miller, logistical support of the US Army's Interim Brigade Combat Team (IBCT) was examined. The IBCT was created by the Army to answer the requirement for rapid deployment that exists to address the many threats faced by the United States throughout the world. The Army is attempting to shift to a capabilities-based force able to respond quickly to various conflicts, from humanitarian efforts to full-scale theater wars. Light

infantry forces, while responsive, do not have the combat capability to create sustained stabilization of a hostile area. Heavy forces, on the other hand, are not mobile enough to fit the rapid deployment requirement. The IBCT was created in an attempt to merge the positive aspects of light and heavy forces; IBCTs are medium size forces with the capability to rapidly deploy and stabilize small-scale conflicts. The simulation study involved modeling and analyzing the receipt, storage, and distribution of munitions to supported units in the IBCT (Bertulis, 2005). Like the ALS study described above, many simplifications and assumptions went into creating the simulation model. For example, several munitions customer units were aggregated into one delivery unit. Despite the simplifications, the authors were able to determine several factors that would significantly impact the flow of ammunition to IBCTs.

Several articles describing significant abstractions in simulation modeling were reviewed (Gatersleben, 1999; Balaban, 2000; Baesler, 2004; Gunal, 2007). In all of the simulation studies examined, the simulation models were scaled to capture the appropriate amount of detail to answer the research objectives that were posed by the customer; simplifying but logical assumptions were used to create feasible simulations of complex real-world systems. Significant abstraction and simplification is necessary in the modeling of base operations for the B-1B due to the great complexity of all the activities involved that are necessary to support daily operations. Furthermore, data and time constraints prevent detailed modeling of many processes that are crucial to base operations. However, the studies covered above show that even with significant abstraction, valuable insight into real-world processes can be gleaned from simulation models.

MSgt Theodore K. Heiman, for his M.S. thesis completed at the Air Force Institute of Technology, used simulation to study the impact that changes to the isochronal inspection process for the C-5 Galaxy would have on aircraft availability. Beginning in October 2009, Air Mobility Command (AMC) reduced the number of active isochronal docks from four to three high-velocity regionalized isochronal docks (HVRISO). C-5 inspection criteria were also modified to follow a Maintenance Steering Group-3 (MSG-3) approach that would overhaul inspection requirements, such as moving all system inspections to PDM. A model of the isochronal inspection process for the C-5 was created, and the effect that the dock consolidation, MSG-3 driven inspection requirements, and various dock selection methods would have on aircraft availability were determined by examining the model outputs for varying levels of each of the three factors and using a generalized factorial design to determine which of the factors were significant. Based on the results of the designed experiment, dock selection methods and consolidation requirements were recommended that would provide the highest level of aircraft availability. (Heiman, 2009)

Although the model of the isochronal inspection process for the C-5 is not directly applicable to the maintenance cycle of the B-1B, the model layout and analysis methodology can be directly applied to the study at hand. The entities in the model were C-5s flowing through multiple cycles of isochronal inspections, which made capturing aircraft availability metrics fairly straightforward. Using a generalized factorial design was a very effective way to determine which of the factors being varied in the model had a significant impact on aircraft availability. Although many activities were not captured by the model, valid recommendations were made that will allow AMC to maximize the

aircraft availability of the C-5 with the new system of isochronal inspections. Aspects of the entity structure of the simulation model and analysis methodology used in MSgt Heiman's thesis research will be applied in this study.

Summary

The development and planned implementation of HVM, driven by the larger AFSSO21 initiative, was based on the Lean and Six Sigma philosophies developed by civilian businesses that seek to eliminate waste and make all processes more efficient. With the ailing B-1B fleet continuing to age, more effective maintenance procedures are necessary to ensure the availability and longevity of this valuable airframe. Though HVM promises to absolve the B-1B fleet from its record of unacceptably low availability rates, analysis is necessary to validate the impact of HVM. DES is the main tool used in this research. Chapter III will cover the development and explanation of the simulation models used in this thesis.

III. Methodology

Chapter Overview

This chapter covers the background and development of the two simulation models created for this study. To assess the impact that HVM for the B-1B will have on base operations, two simulation models were created: a current-state simulation model of base operations, and a future-state simulation model based on the proposed changes to base operations under HVM. Current base maintenance and supply processes at Ellsworth AFB, SD are briefly summarized to show what drove the development of the models. The conceptual model development is explained, and the simulation model of current base operations created in ARENA 12 is thoroughly examined.

The significant differences for base operations under HVM are briefly summarized. Based on the proposed changes to the B-1B maintenance cycle, the development of the HVM conceptual model is explained, and the simulation model of base operations under HVM created in ARENA 12 is covered in detail.

Summary of the 28th Bombardment Wing

Ellsworth AFB, located about seven miles east of Rapid City, SD, is home to several important aircraft and programs that are crucial to the US Air Force. Ellsworth AFB has housed the 28th Bombardment Wing since 1947, when the B-29 Superfortress was flown. In 1986, the 28th Bombardment Wing became the home of the B-1B (SAC Bases, 2009).

Currently, the 28th Bomb Wing consists of the 28th Maintenance Group, the 28th Operations Group, the 28th Medical Group, and the 28th Mission Support Group (Ellsworth AFB Home, 2009). The 28th Operations Group consists of three squadrons: the 28th Operations Support Squadron, which plans and supports combat operations for the two tactical B-1B squadrons, which are the 34th and 37th Bomb Squadrons. There are 28 B-1Bs assigned to Ellsworth AFB, SD; the planes are split evenly between the 34th Bomb Squadron and the 37th Bomb Squadron (Pedersen, 2009). The 28th Maintenance Group, which exists to provide maintenance support to ensure combat-ready B-1Bs, consists of four squadrons: the 28th Aircraft Maintenance Squadron, the 28th Maintenance Squadron, the 28th Munitions Squadron, and the 28th Maintenance Operations Squadron. The layout of the 28th Bomb Wing is shown in Figure 1.



Figure 1. Structure of the 28th Bombardment Wing

Development of the Current State Conceptual Model

The ultimate goal of the simulation study at hand is to determine the effect that the implementation of HVM will have on the operations of the 28th Bomb Wing. Due to the complexity of all of the interactions between the squadrons of the 28th Bomb Wing that occur in daily operations, a significant amount of abstraction was used in creating the simulation model. Furthermore, HVM for the B-1B is still in its developmental stages; there are many processes that will be implemented under HVM that have not been laid out in detail. However, the changes to the flow of aircraft through the base maintenance process under HVM have been fairly well-defined. Under HVM, each B-1B will undergo depot maintenance more frequently, but will remain at the depot for much less time per visit. Depot maintenance will also be more synchronized with base maintenance. Since changes to the base maintenance process will definitely occur under HVM, the development of the two simulation models of base operations was geared to focus on high-level maintenance actions that can be explicitly and accurately modeled based on existing historical data.

The Scheduled Inspection and Maintenance Requirements technical manual for the B-1B aircraft (Technical Order (TO) 1B-1B-6) outlines all of the required scheduled maintenance inspections for the B-1B. The B-1B is a very demanding aircraft in terms of maintenance; each B-1B requires a myriad of scheduled maintenance to ensure combat readiness. A summary of the different categories of scheduled aircraft maintenance outlined in TO 1B-1B-6 are shown in Table 1.

Table 1. Different Categories of Scheduled B-1B Maintenance

Scheduled Inspections	Special Requirements	Replacement Schedules
Pre-Flight Inspections	Inspections after a specific occurrence	Crew Communication Items
Quick Turn Inspections	Programmed Depot Maintenance	Electrical Power
Hourly Post-Flight Inspections	Functional Check Flight Inspections	Fire Protection
Alert Inspections	30 and 90 Day Inspections	Navigation
Engine Conditioning		Oxygen
Quick Turnaround (Conditional)		Accessory Gearboxes
Limited JEIM (Conditional)		Crew Escape/Safety
Refurbishment		

Each scheduled maintenance action has specific checks and replacements that are required, and various maintenance personnel are assigned to each action based on requirements, availability, and level of expertise.

Along with all of the scheduled maintenance, there is a significant amount of unscheduled maintenance that occurs on all B-1B aircraft. Based on historical data from previous years, approximately 86 percent of base maintenance actions for the B-1B are unscheduled (Malone, 2009). Currently, the B-1B is on a “fly until failure” system. In other words, unless a part is specifically scheduled to be replaced according to TO 1B-1B-6, each aircraft will continue to carry out daily sorties until a failure that renders the plane unable to fly is experienced (Milnes, 2009). Once the failure occurs, the aircraft must be fixed before it can return to flying.

The main difference for base operations under HVM is that there will be a restructuring of scheduled base maintenance. Therefore, to compare current-state base operations to base operations under HVM, scheduled maintenance needs to be modeled explicitly to some degree. Since the flow of aircraft through the base maintenance process would be the most significant portion of the model, making the B-1B aircraft the

entities flowing through the model made the most sense. Due to time and data constraints, modeling all of the scheduled maintenance outlined in TO 1B-1B-6 would not be possible. However, there are several major scheduled inspections with clearly defined timelines that play a significant role in the flow of the B-1B through its maintenance cycle. These inspections are HSCs, Periodic Isochronal Inspections (ISOs), Avionics End-to-End Checks, and PDM. HSCs are accomplished 150 days \pm 15 days following the completion of the previous scheduled HSC inspection. ISOs are divided into two categories: major ISOs and minor ISOs. Minor ISOs are accomplished 900 days \pm 30 days following completion of the previous scheduled minor ISO. Major ISOs are accomplished 1800 days \pm 30 days following completion of the previous scheduled major ISO. Avionics End-to-End Checks are accomplished 450 days \pm 30 days following completion of the previously scheduled Avionics End-to-End Check. Each B-1B is also due for PDM once every 1800 days \pm 30 days. When a plane is undergoing PDM, time does not accrue towards its scheduled on-base inspections. If HSCs, major or minor ISOs, or other major scheduled inspections are due at the same time that an aircraft is scheduled to complete PDM, these inspections will be handled by the depot during PDM. (TO 1B-1B-6, 2007)

Along with the scheduled maintenance described above, the unscheduled maintenance that occurs on base must also be incorporated into the model, or the flow of each plane through the maintenance process would be very unrealistic, since such a significant portion of base maintenance is unscheduled. However, unlike scheduled maintenance, unscheduled maintenance does not occur at regular intervals. Fully deterministic schedules for the B-1Bs flowing through the model would therefore not be

possible, since failures and subsequent unscheduled maintenance will occur randomly between each scheduled maintenance inspection. Logic has to be created that can handle sending each B-1B to scheduled maintenance stations based on the time intervals outlined above while incorporating the random failures that can occur as daily operations unfold.

A significant amount of the delays involved in unscheduled maintenance are caused because a part may fail that is not available for immediate issue. If a replacement part is not readily available, it must be ordered through the supply chain of the 28th Bomb Wing. Although there are several different avenues for supplying parts that are available, the supply process can be very lengthy, since a specific part that requires replacement may be scarce. While the maintainers are waiting for a part to arrive, the B-1B that requires the replacement part is often not mission capable (MC). Therefore, to model unscheduled maintenance in a reasonable fashion, delays incurred through the supply chain must also be included.

Deployment is another significant event for each B-1B since deployments cause aircraft to be off base for extended periods of time. However, based on discussions with subject matter experts, there is not a set system for assigning deployments; the frequency of deployments for each aircraft can be vastly different. Furthermore, there is currently no change planned for the way deployments are assigned and executed with HVM. It was therefore decided that deployments would not be explicitly captured in our simulation. However, this does not cause the flow of aircraft through the maintenance process to be unrealistic, since time will still accrue for major inspections while an aircraft is off station.

Since the simulation study is focused on major maintenance inspections, modeling daily on-base sortie generation and execution, along with all of the preflight and post flight inspections that must occur before each B-1B is flown (TO 1-B1-B6, 2007), was not considered. If the B-1B is not involved in a maintenance process or a deployment, it will be assumed that the B-1B is undergoing normal base operations. Many of the minor maintenance processes that were ignored can be assumed to be folded into the “normal operations” process. Although the time an aircraft will spend in normal operations will not directly correspond to the amount of time that it will be MC due to all of the scheduled maintenance and crew operations that are being abstracted out of the model, it is reasonable to assume that longer times in normal operations will be proportional to longer periods of MC status. While the plane is undergoing scheduled maintenance, PDM, or breaks and requires unscheduled maintenance, it is not MC, and time will not accumulate in normal operations.

The flow of each B-1B through the current state base operations model occurs as follows: First, an appropriate number of B-1Bs are created based on the number of available aircraft at Ellsworth AFB. Each aircraft is assigned times to each of its next scheduled inspections, which are staggered so that the planes flow through the maintenance cycle in a realistic manner and do not queue up at maintenance stations as a result of poor scheduling. After receiving its initial schedule, each aircraft spends time in a normal operations process block, which is an abstraction of the real world operations of the B-1B. The normal operations block represents the activities of each aircraft while it is in MC status. Each aircraft remains in normal operations until its next scheduled inspection or until it experiences a random failure that requires unscheduled maintenance.

Once the current maintenance action is completed, the times to the aircrafts' next scheduled inspection are adjusted based on the amount of time spent in the current maintenance action. Each aircraft then cycles back to normal operations until its next scheduled maintenance inspection or until a failure occurs. The flow of B-1Bs through the base operations model is shown in Figure 2.

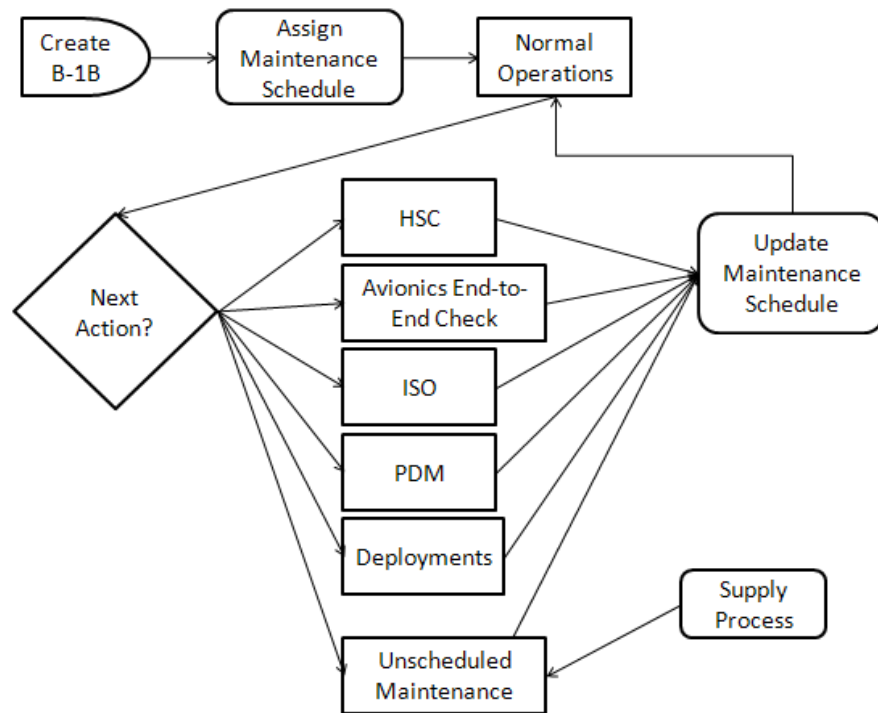


Figure 2. Conceptual Flow of Current State Base Operations Model

When an aircraft fails for unscheduled maintenance, maintainers often cannot begin necessary maintenance due to unavailable parts. The time that an aircraft spends down due to unavailable parts is referred to as Not Mission Capable due to Supply (NMCS). Based on NMCS time for each aircraft on base, the Total Not Mission Capable

due to Supply rate (TNMCS) is computed, which is used to assess the efficiency of the base supply chain (Milnes, 2009). A high TNMCS rate indicates that for a given period of potential operation time, an aircraft is not MC for a significant portion of time due to unavailable parts. Since TNMCS is a significant metric, the base supply process is modeled with enough detail to capture an accurate representation of how HVM could potentially affect TNMCS rates.

When an aircraft requires unscheduled maintenance, it does not always require a part replacement. If a part is not required, maintenance can be completed with no delays, assuming that the necessary maintainers are available and a maintenance dock is free. If a part is required, maintenance ceases until the part becomes available. If the required part is located on base, it is usually issued during the next daily maintenance cycle, but can be delivered to the maintainers more promptly if deemed necessary. However, if the part is not readily available, it must be obtained through various avenues of supply, such as through an AFMC depot (Milnes, 2009). This process is detailed in Figure 3.

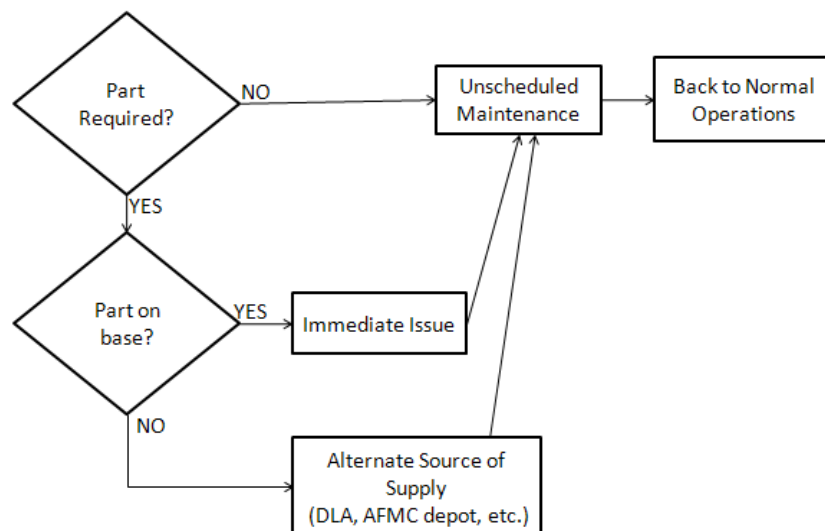


Figure 3. Conceptual Flow of Supply Process Piece of Unscheduled Maintenance

Since the implementation of HVM will definitely alter the flow of B-1Bs through PDM and the base maintenance cycle, our final models focus on following several B-1B aircraft through scheduled base and depot maintenance, along with other significant activities that render the aircraft not mission capable (NMC). The time each aircraft spends in normal operations is the most significant indication of a difference under HVM, since the normal operations time relates closely to MC time. The base supply process is also modeled in some detail to capture some supply-related metrics, such as TNMCS.

Modeling Assumptions and Limitations

Due to the complexity of the maintenance operations conducted on the B-1B at Ellsworth AFB, a large amount of minor maintenance actions are not captured in the model. The only scheduled maintenance inspections explicitly modeled are HSCs, ISOs, Avionics End-to-End Checks, and PDM. Therefore, the time that each aircraft spends in the normal operations process described earlier does not directly relate to MC time; the time each aircraft spends in normal operations should be higher than the actual MC time, since there are maintenance activities not being captured that would cause each aircraft to be in NMC status. Furthermore, the significant amount of abstraction involved in creating the normal operations process prevents an accurate modeling of the utilization rates of base maintainers. Sorties, pre-flight, post-flight, and various minor maintenance activities that are not being explicitly modeled require varying amounts of maintainers with different qualifications and areas of expertise. The resources included in the model and their respective utilization rates are therefore not an accurate representation of the

utilization of base maintainers in real-world base operations, but are still be useful in giving some indication of the manpower differences that will occur under HVM.

The scheduled maintenance explicitly modeled excludes much of what really occurs in actual maintenance. Only the delays associated with each scheduled inspection were modeled. In addition to abstracting the maintenance worker utilization, there is no attempt to capture how each of the scheduled maintenance inspections put additional demands on the base supply chain. However, HSCs, ISOs, and Avionics End-to-End Checks follow strict checklist procedures, and the parts that are commonly required to be replaced are often stocked (Milnes, 2009). Furthermore, the times used to fit distributions for HSCs, ISOs, and Avionics End-to-End Checks included any additional time that an aircraft may have been held due to unavailable parts. The delays fitted for each scheduled maintenance inspection are therefore assumed to adequately capture the delays that may occur due to unavailable parts and will reflect reasonable NMC times while each jet passes through.

Deployments were also not captured in the model, which drove the amount of aircraft that were generated. The amount of aircraft that are on base going through daily operations and routine base maintenance varies significantly (Pedersen, 2009). However, based on particular dates given by maintenance personnel, of the 28 B-1Bs assigned to the 34th and 37th BS, there were between 10-15 aircraft on station, and between 1-4 aircraft undergoing PDM at any point in time (Pedersen, 2009). The other aircraft were either deployed, being repaired off base, or taking part in a special duty, such as an air show. Sixteen aircraft are created in the model. For the current state model, the PDM cycles of each aircraft are staggered so there are two B-1Bs due for PDM at roughly the

same time, and both aircraft will likely finish before the next two are due. This way, the amount of aircraft that are on base and at the depot for PDM at any given time is a reasonable approximation of reality.

There are several assumptions made in the creation of the unscheduled maintenance piece, which is identical for the current state and HVM model. Specific part breaks and replacements are not explicitly modeled, but the delays in maintenance associated with the base supply chain are captured. Specific part breaks are not modeled due to time constraints, and data was not readily available to determine a reasonable approximation of the amount of parts that are required for a typical unscheduled maintenance action. When an unscheduled failure occurs, it is therefore assumed that one part is required, though this is not always the case in reality. If the required part is not located on base, then the plane will be delayed for an appropriate amount of time based on a draw that will determine which source of supply the part comes from. This results from the assumption of one part per break; in reality parts can arrive from several different avenues of supply (Milnes, 2009). Although parts are not modeled as resources, the delays associated with the supply process are captured with enough detail to reflect how NMCS times impact the amount of time each aircraft spends in normal operations. The unscheduled maintenance piece also excludes the possibilities of planes being in depot status for maintenance beyond homestation capability. Failures can occur that base mechanics are not able to repair, either due to a lack of available equipment or expertise (Pedersen, 2009). It is assumed that whenever an unscheduled failure occurs in the models, the aircraft are always repaired on base. This assumption therefore causes a

slight overestimation of the time that aircraft spend in normal operations, since there is no chance that any B-1B will fail and require lengthy depot repairs that render them NMC.

Current State Model Description

The model of current state base maintenance operations can be divided into four pieces: generation, normal operations, scheduled maintenance inspections, and unscheduled maintenance. A description of each piece of the model, along with important logic and an explanation of the data used to fit each process, follows.

B-1B Generation

The first piece of the model generates the sixteen aircraft, assigns a time to next failure for each aircraft, and assigns a unique maintenance schedule to each aircraft. The generation portion of the model is shown in Figure 4.

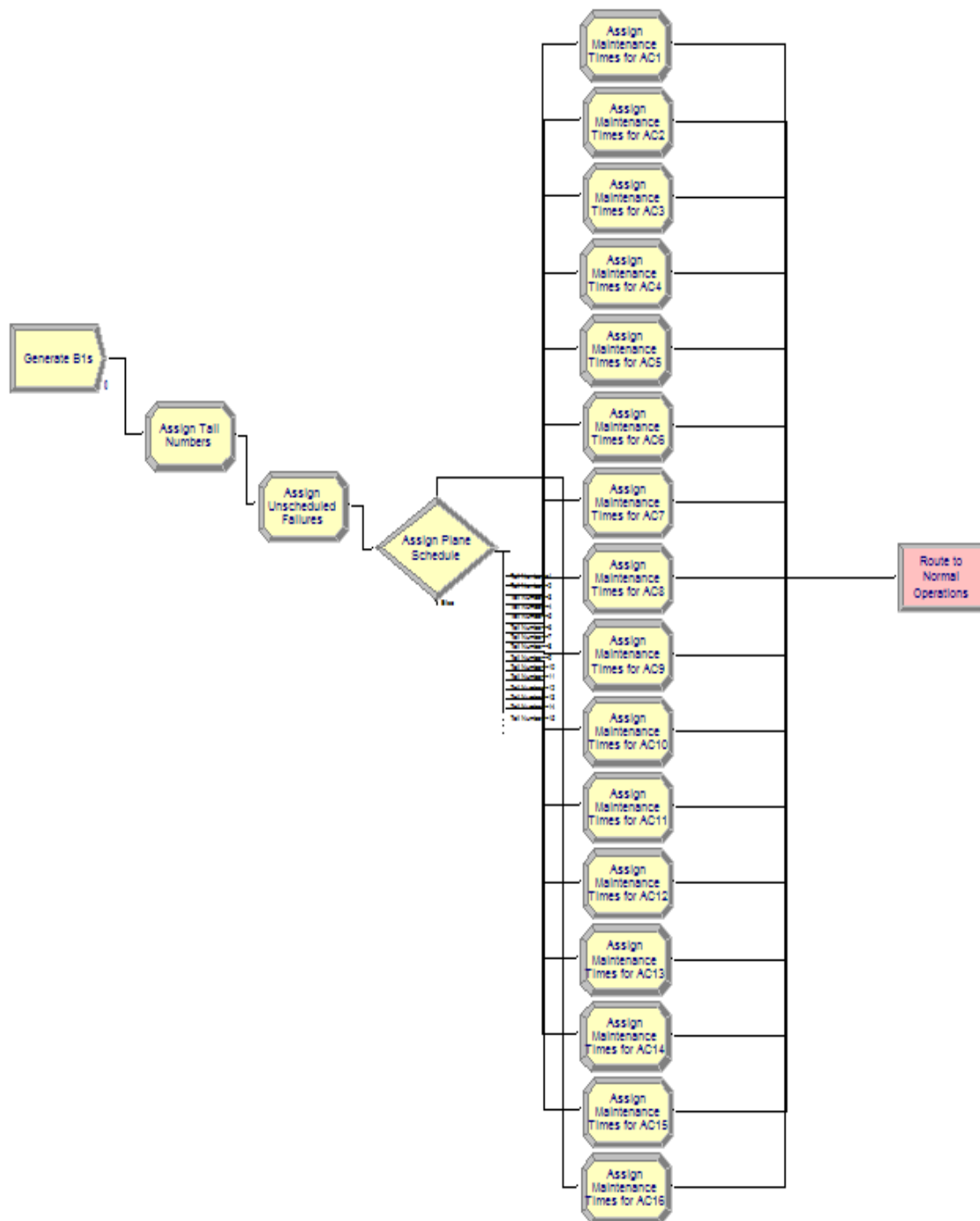


Figure 4. Generation portion of the Current State Model

As each B-1B is created, it is assigned a tail number, which is used to assign a different maintenance schedule to each of the aircraft. Once each aircraft is assigned a tail number, it is assigned a random time to its next failure. The time between failures was calculated based on data pulled from the Logistics, Installations, and Mission Support-Enterprise View (LIMS-EV) database by Mr. Fortunato Nepomuceno, an analyst in the Performance Analysis Branch of HQ AFMC. The spreadsheet provided listed the dates and lengths of all unscheduled maintenance activities that were performed on each of the B-1Bs currently in the fleet. To fit an appropriate distribution for the time to next failure for each aircraft, the data was sorted by aircraft tail number, and the times between unscheduled maintenance over a three year period, from 2006 to 2009, were computed for three B-1Bs at Ellsworth AFB. Since the times were based on calendar dates, the times between unscheduled maintenance actions were captured in days. Although the exact amount of hours between each unscheduled maintenance action was not available, the amount of days between failures provides an appropriate level of fidelity for the processes being captured in the model.

Once each aircraft is assigned a time to its next failure, tail numbers are used to route each aircraft to a unique assign module that assigns each aircraft different times, in days, to its next HSC, ISO, Avionics End-to-End check, and PDM. This is accomplished by using a spacer variable for each inspection. Once full times to each of the inspections are drawn, each aircrafts' times are multiplied by a unique integer value (between zero and 15) and a spacer variable that ensures that all of the aircraft are staggered appropriately through the base maintenance cycle. This method ensures that there are not an excessive number of jets scheduled for the same maintenance inspection at the same

time. Note that the spacer variable is always less than $1/15$, which ensures that each of the assigned times to all of the next scheduled maintenance inspections do not exceed the maximum amount of time that is allotted between each inspection.

In addition to time between scheduled maintenance, the time of each maintenance activity is also assigned, which is set to the current time between scheduled maintenance plus the current simulation time. Although the time between each maintenance inspection is equal to the time of each maintenance inspection at this phase in the model (since the current simulation time is zero), the time of each maintenance inspection is necessary to properly adjust scheduled maintenance times later in the model. A summary of each of the attributes assigned to the 16 aircraft in the generation phase of the model are summarized in Table 2. All fitted distributions have units of days. Note that the X used in the table represents the integer value used for each aircraft tail number, where X is an integer from 0 to 15. The ANINT function rounds the argument to the nearest integer and the MX function returns the maximum of the argument.

Table 2. Attributes assigned to each aircraft during generation phase

Attribute	Description	Expression
TNF	Time to next failure	$MX(0, ANINT(-0.001 + WEIBULL(2.33, 0.472)))$
TNHSC	Time to next HSC	$ANINT(X * HSC \text{ spacer} * UNIFORM(135, 165))$
TNISO	Time to next ISO	$ANINT(X * ISO \text{ spacer} * UNIFORM(870, 930))$
TNAVIONICS	Time to next Avionics Check	$ANINT(X * AV \text{ spacer} * UNIFORM(420, 480))$
TNPDM	Time to next PDM	$ANINT(X * PDM \text{ spacer} * UNIFORM(1770, 1830))$
TofHSC	Time of next HSC	$TNHSC + TNOW$
TofISO	Time of next ISO	$TNISO + TNOW$
TofAVIONICS	Time of next Avionics Check	$TNAVIONICS + TNOW$
TofPDM	Time of next PDM	$TNPDM + TNOW$

After all of the attributes are assigned, each aircraft is routed to the normal operations phase of the model. No aircraft will return to the generation portion of the model for the remainder of the simulation.

Normal Operations

The normal operations phase of the model holds each aircraft in the Normal Operations process block until the time to its nearest maintenance action expires. The normal operations portion of the model is shown in Figure 5.

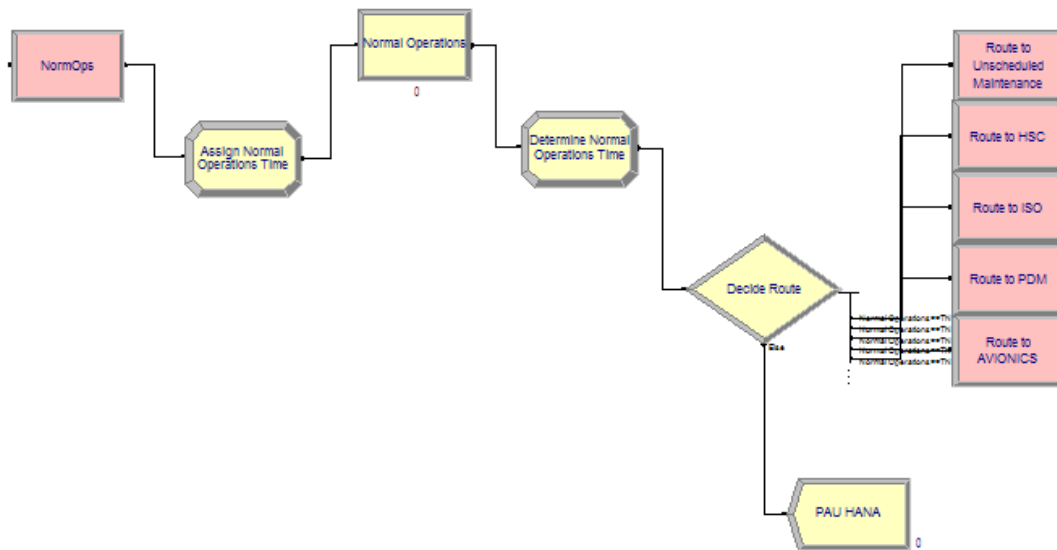


Figure 5. Normal Operations portion of the Current State Model

In the first assign block, each aircraft's time in normal operations is determined based on the minimum amount of time to either its next failure or next scheduled maintenance action and assigned as an attribute to each aircraft.

$$Normal\ Operations = \min(TNF, TNHSC, TNISO, TNAVIONICS, TNPDM)$$

Each aircraft will then delay in the Normal Operations block for the amount of days stored in the *Normal Operations* attribute. Once the time in normal operations expires, each aircraft is routed to its appropriate maintenance activity based on a conditional decide node. For each aircraft, the *Normal Operations* time will match either the time to next failure or a time to next scheduled inspection, which is used to route each aircraft to the correct station based on the earliest activity.

Scheduled Maintenance Inspections

For scheduled maintenance inspections, the model includes HSCs, ISOs, Avionics End-to-End Checks, and PDM. The base maintenance inspections are shown in Figures 6-8.

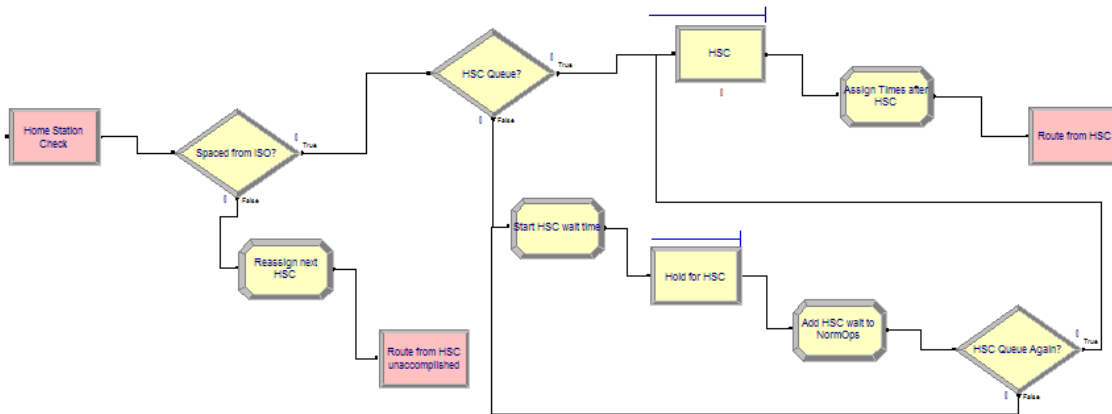


Figure 6. HSC portion of the Current State Model

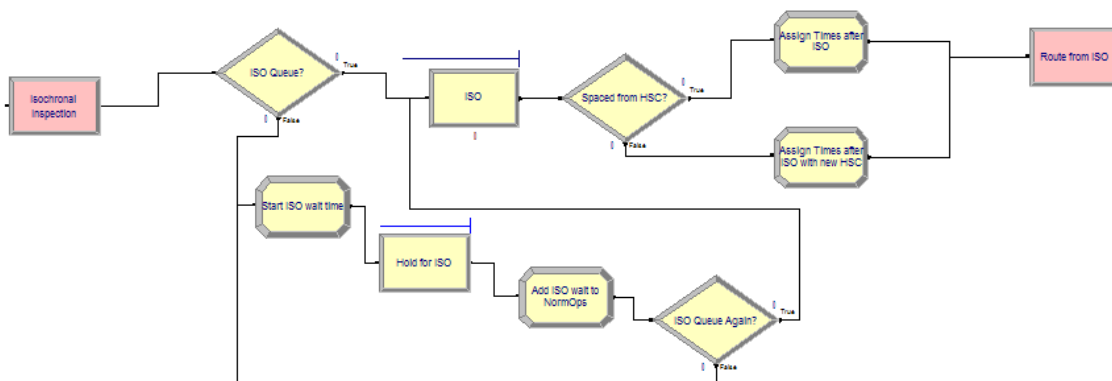


Figure 7. ISO portion of the Current State Model

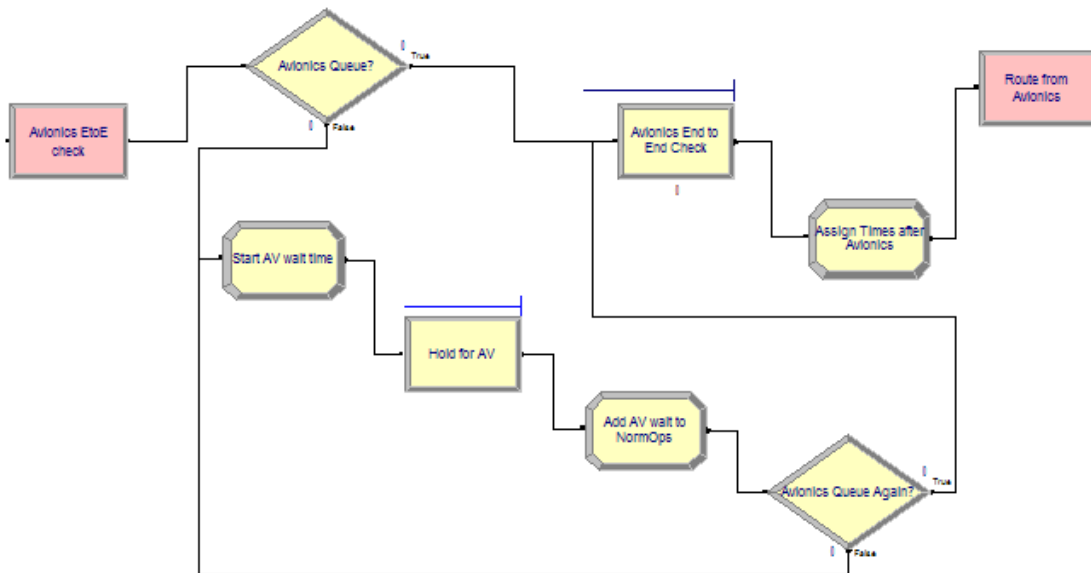


Figure 8. Avionics End-to-End Check portion of the Current State Model

The basic logic for HSCs, ISOs, and Avionics End-to-End Checks are all the same. Based on conversations with maintenance subject matter experts, aircraft are almost always staggered to flow through the maintenance cycle without backing up at any station. In other words, there should never be an instance where several jets are NMC because they are waiting to undergo the same inspection, since there is only one available team for each type of inspection (Mroczkowski, 2009). Resources, referred to as “teams” in the model, are required for each of the three base maintenance inspections. Each maintenance process uses the majority of the team resource, which ensures that only one aircraft can undergo each type of inspection at a time. The flexibility allotted for the time between scheduled maintenance inspections outlined in TO 1-B1-B6 allows for schedulers to schedule aircraft so that each station is never overwhelmed. To handle this

behavior in the model, when a B-1B goes to an HSC, ISO, or Avionics End-to-End Check, there is a decide node in place to determine if there is another aircraft undergoing the same activity. If an aircraft is present, then the incoming aircraft will hold until the inspection is completed on the previous jet. The hold time is added to the total normal operations time, since it is assumed that during this hold period, the jet will not experience a failure during normal operations. This is a reasonable assumption, since the B-1Bs are initially staggered appropriately, and planes do not spend a significant amount of time in the hold condition for any of the scheduled inspections.

If an aircraft is due for an HSC and an ISO at around the same time (the allotted time windows overlap), the plane will accomplish the HSC during the ISO (Pedersen, 2009). Logic is included in the model to capture this behavior. If an HSC is close enough to an ISO, the HSC is not accomplished, the time to the next HSC is redrawn, and the plane then completes an ISO. Additionally, if an HSC is scheduled close after the completion of an ISO, the HSC is assumed to be accomplished during the ISO, and the time to the next HSC is redrawn.

After each scheduled maintenance inspection is completed, the time to each of the next inspections is reduced based on the amount of time the aircraft spent in the current inspection. The time to the next current inspection and a new time to the next failure is redrawn, and each aircraft is then routed back to the normal operations portion of the model.

Since capturing the operations that occur at the depot is not a focus of the simulation study at hand, the PDM portion of the model is relatively simple. When an aircraft is due for PDM, it is routed to the PDM process block, which is simply a delay

with multiple aircraft allowed at the depot simultaneously. Once the PDM delay is completed, the times to each of the scheduled base maintenance inspections are not adjusted, since time does not accrue towards the scheduled base maintenance actions when an aircraft is in PDM (TO 1B-1B-6, 2007). The time to the next PDM and the time to its next failure is redrawn, and the aircraft is routed back to the normal operations portion of the model.

The distribution used to draw times for ISOs was fitted based on data provided by the ISO team at Ellsworth AFB, SD. The length of times, provided in days, for each ISO accomplished from January 2008 to August 2009 was used. The distribution used to draw times for the PDM delays came from actual recorded PDM flow days for the aircraft of the 34th and 37th BS from 2005 to 2009. Although data was not easily accessible in LIMS-EV to fit distributions for the lengths of HSCs and Avionics End-to-End Checks, accurate time estimates were provided by maintenance experts at Ellsworth AFB, SD (Pedersen, 2009). Triangle distributions are used to capture the minimum, maximum, and most likely length of HSCs and Avionics End-to-End Checks. A summary of the distributions used in these processes is shown in Table 3 (all units in days).

Table 3. Fitted and Estimated distributions for Scheduled Maintenance Inspections in the Current State Model

Process	Distribution
HSC	ANINT(TRIANGLE(3,4,6))
ISO	MX(13,ANINT(12.5+LOGN(10.3,13.5)))
Avionics End-to-End Check	ANINT(TRIANGLE(3,5,10))
PDM	MX(116,ANINT(116+EXPO(44)))

Unscheduled Maintenance

When an aircraft's time in normal operations matches the time to its next failure, this indicates that the aircraft failed before any scheduled maintenance and the aircraft is routed to the unscheduled maintenance portion of the model. However, if an aircraft fails close enough to a scheduled inspection, the aircraft is immediately routed to the appropriate scheduled inspection and does not progress through unscheduled maintenance. This logic approximates the way that unscheduled maintenance is often deferred to a scheduled inspection that is sufficiently close.

Although part acquisition and replacement is not explicitly modeled, the delays associated with the base supply chain are present in the model. The percentage of time that a part is available for immediate issue is based on the stockage effectiveness rates that were recorded during 2009, which indicate the percentage of time that a part required for unscheduled maintenance was available on base (Milnes, 2009). The average of all the stockage effectiveness rates from all sources of supply was used as the percentage of time that a part is available for immediate issue in the model. If a part is available for immediate issue, the plane will be delayed for one day, since available parts are usually delivered during the next daily maintenance delivery cycle (Milnes, 2009). If a part is not available for immediate issue, the NMCS time begins, and the plane delays based on the different avenues of supply that are available. The initial logic that models deferred maintenance and the supply chain delays are shown in Figure 9.

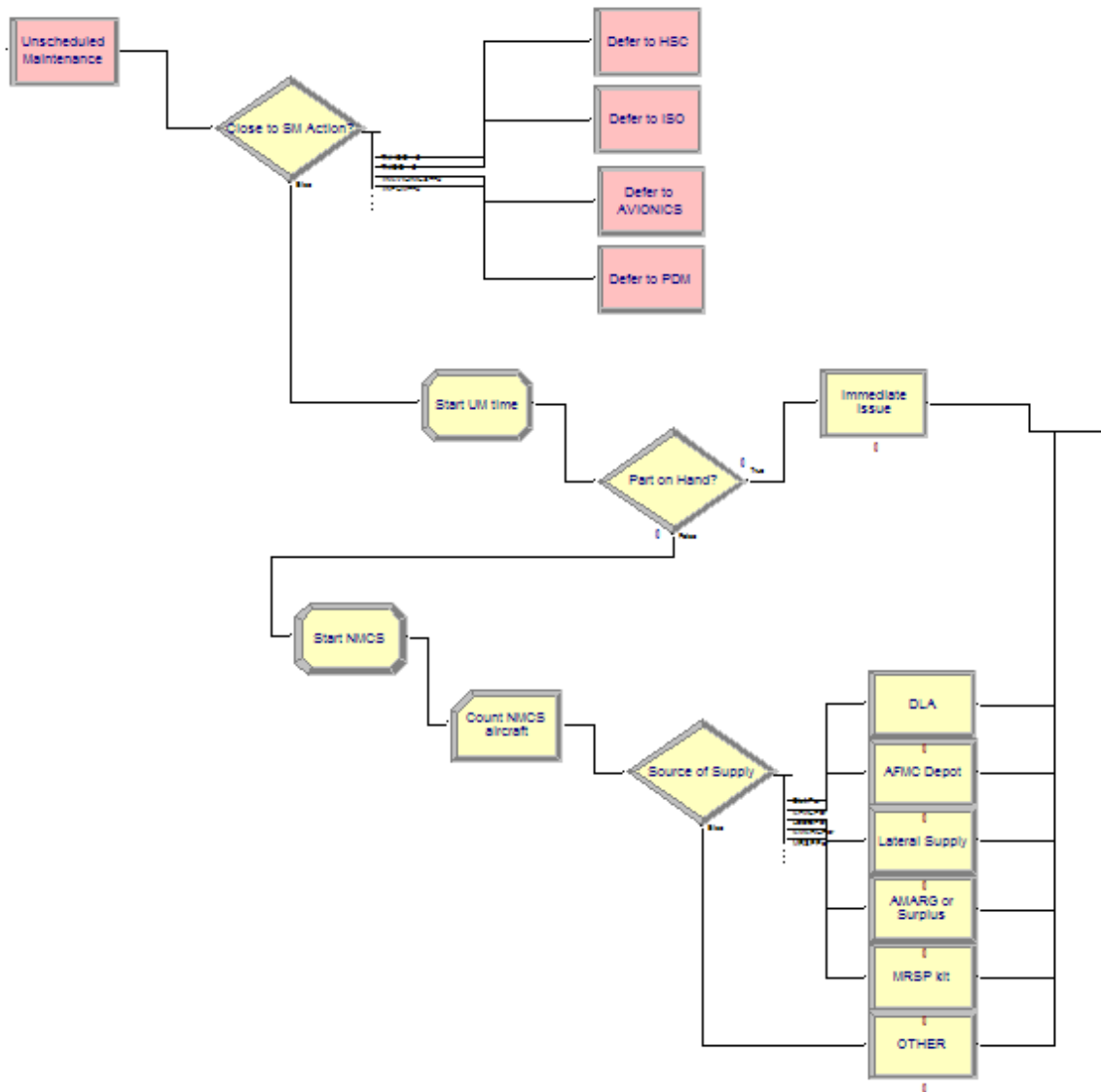


Figure 9. Initial Unscheduled Maintenance portion of the Current State Model

Since it is assumed that there is only one part replacement per failure, once an aircraft starts NMCS time, the plane delays based on the times associated with one avenue of supply. The percentage of time that a plane goes to each particular avenue of supply, and the distributions fitted for the actual delays associated with each possible supply route, are determined based on data provided by the 28th Logistics Readiness

Squadron at Ellsworth AFB, SD. The data provided by the 28th LRS lists every MICAP condition that occurred at Ellsworth AFB since February 2005. For each MICAP condition, the length of time that the B-1B was NMCS, along with the delete code that reflected the source of supply for the MICAP part, was available. Specific avenues of supply used in the model are not driven by whether or not a required part was consumable or reparable, which is what occurs in reality. However, since part acquisition and replacement is not being explicitly modeled, using percentages to determine the supply source for each failure was the closest approximation available. The sources of supply included in the model are based on all of the delete codes that were listed on the spreadsheet provided by the 28th LRS. A summary of the percentage of parts obtained from and delay distributions for each avenue of supply are shown in Table 4 (units in days).

Table 4. Supply Percentages and Delay Distributions calculated for Alternate Supply Sources

Supply Source	Percentage Supplied	Delay Expressions
DLA	26.81%	$MX(1, ANINT(-0.001 + LOGN(6.05, 18.1)))$
AFMC Depot	24.66%	$MX(1, ANINT(-0.001 + WEIBULL(10.7, .88)))$
Lateral Supply	14.71%	$MX(1, ANINT(-0.5 + LOGN(4.26, 3.53)))$
AMARG/Surplus	4.90%	$MX(1, ANINT(-0.5 + LOGN(15, 13.4)))$
MRSP Kit	1.13%	$MX(1, ANINT(-0.5 + LOGN(5.77, 11.2)))$
Other	27.79%	$MX(1, ANINT(GAMMA(8.15, 0.674)))$

Once an aircraft completes the supply portion of the model, it is delayed at the unscheduled maintenance process block, which represents the execution of unscheduled maintenance. Resources are allocated to the unscheduled maintenance process to reflect the limited amount of maintenance personnel that are available on base. The times used to fit the distribution used for the length of each unscheduled maintenance action came

from the same data that was used to fit the time between failures, since the spreadsheet also contained the length, in days, of each unscheduled maintenance action.

The unscheduled maintenance portion of the model captures the time each aircraft spends in unscheduled maintenance, along with the NMCS time associated with each unscheduled failure. Once an aircraft completes unscheduled maintenance, all of the times to its next scheduled inspections are reduced based on the total amount of time the aircraft was in unscheduled maintenance. A new time to next failure is drawn, and each aircraft is then routed back to normal operations.

Since all times used to fit the distributions used in each process in the model were reported in days, the base unit for the model is days. Consequently, the amount of hours within each day of the simulation is irrelevant, and each day that passes in the simulation represents a generic work day that occurs on base. There is no modeling of maintenance team schedules, weekends, or holidays since each day that passes in the simulation is assumed to be a work day.

Changes to Base Operations Under HVM

Under HVM, several changes to base operations are captured by altering pieces of the current state model. The most significant changes are to the structure of scheduled maintenance inspections. ISOs are completely eliminated, and each aircraft will go to the depot for PDM once every 15 months instead of once every 5 years. Since each aircraft is undergoing depot maintenance 4 times as much, PDM flow days for each visit are greatly reduced; each aircraft has about 22 flow days per depot visit. Furthermore, the HSCs, which still occur at 5 month intervals, are synchronized with each PDM

inspection. In other words, in the 15 month PDM cycle, only 2 HSCs are accomplished on base. The third HSC is accomplished off base during PDM. In addition to a planned reduction in total depot flow days, since each aircraft will undergo depot maintenance more frequently, depot maintainers have more opportunities to repair ailing parts or systems, which should lead to a reduction in unscheduled base maintenance. (Rooker, 2009)

The concept of kitting, a key piece of HVM, is currently being developed for the B-1B. The kitting concept is the result of an effort to promote a mechanic-centric focus under HVM, where mechanics have all of the necessary maintenance tools and replacement parts readily available on base. This enables mechanics to begin crucial maintenance actions without unnecessary delays (Rooker, 2009). Although the methods of kitting have not been developed, the intended effect of kiting is that replacement parts that are frequently required are more effectively stocked on base. TNMCS rates are projected to improve, and aircraft MC rates should increase.

Since HVM for the B-1B has not yet gotten past its pilot stages, the full effect that it will have on base operations cannot be determined. Additionally, the additional strain put on the depot with more aircraft flowing through cannot be understood with certainty, and the 22 flow day goal for each PDM inspection may not be achieved. It also remains to be seen whether or not the expedited PDM cycles will serve to improve aircraft failure rates. The age of the B-1B fleet is increasing, and part or system failures are likely to become more common. However, the changes to scheduled base maintenance inspections are well-outlined and can be captured by modifying the current state model of base operations. To assess the possible impact of HVM on the 28th Bomb Wing, the

scheduled maintenance portion of the current state model is modified to implement the changes outlined earlier in the section.

HVM Model Description

To reflect the changes to base operations captured in the current state model under HVM, the scheduled maintenance portion of the current state model is modified as shown in Figure 10. The ISO portion of the model is removed, and the resources allocated to the ISO process are redistributed to the unscheduled maintenance team to reflect the additional maintenance crews available once ISOs are eliminated. HSCs are also synchronized with the PDM cycle. Approximately once every 150 days, the aircraft are sent to the PDM cycle portion of the model, which includes HSCs and PDM. A counter is introduced to track where each aircraft is in its PDM cycle. After completing PDM, each aircraft undergoes two HSCs before returning for another PDM approximately 15 months later. The amount of time that each aircraft spends in PDM is also modified to match the planned PDM flow days under HVM. The HSC and PDM processes in the HVM model are shown in Figure 10.

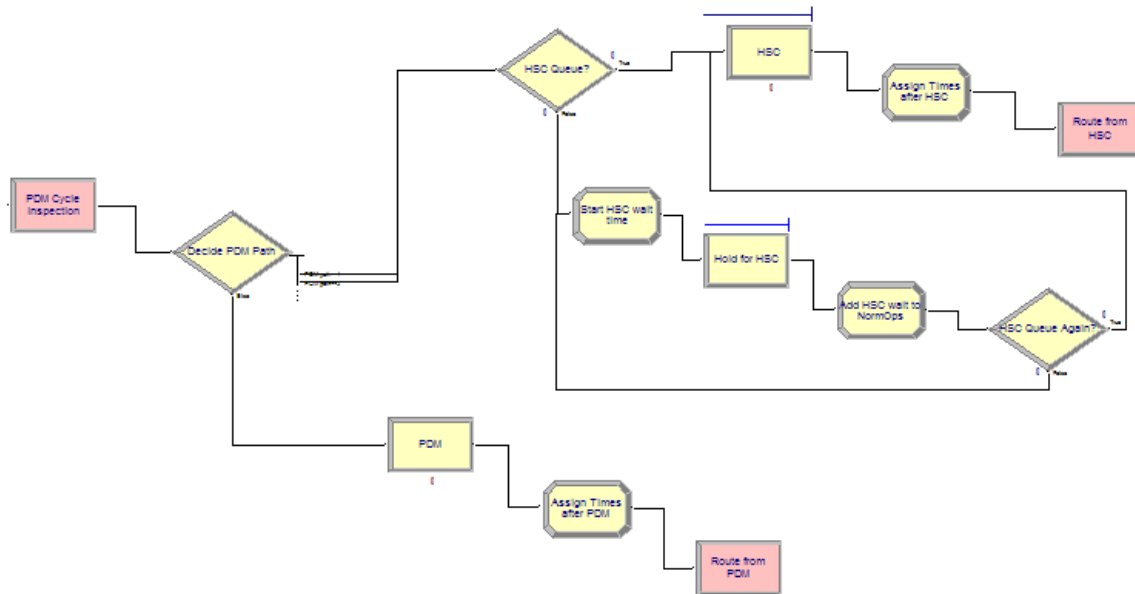


Figure 10. HSC/PDM Portion of the HVM Model

Minor modifications are made with the spacer variables in the HVM model to create a sensible flow for all aircraft through the PDM cycle under the altered timelines introduced by HVM. All other portions of the model remain identical to the current state model. The HVM model still includes the same Avionics End-to-End Checks and unscheduled maintenance pieces of base operations that are in the current state model.

To account for the uncertainty involved in the projected PDM flow days and in the forecasted improvements in aircraft failures with HVM, two variables are created to allow for easy variation of the PDM flow days and aircraft failures that are used in subsequent analysis. A uniform distribution is created to determine the PDM flow days for each aircraft. The estimate of 22 days provided by subject matter experts is used as the lower bound of the distribution, while the upper bound is included in the model as a variable, which allows the maximum PDM flow days per visit to be easily varied, and

allows the impact of longer PDM visits to be analyzed. Another variable, called the maintenance improvement factor (MIF), is created in the model to allow for failure times to be modified. Every time a random failure time is drawn in the HVM model, it is multiplied by the MIF variable. If the variable is set to a value greater than 1, then all of the times to the next failure that are drawn are increased, signifying an improvement in aircraft failure rates. Since the effect that HVM will have on aircraft failure rates is not certain, the failure variable allows the failure rates to be easily modified, which is useful in the comparisons between the current state and HVM models.

Verification and Validation of the Simulation Models

The logic used to route each aircraft through the model is tested extensively to ensure proper operation. A test scenario is created for both models in which only one B-1B is generated. The initial assignments to each of the aircraft's scheduled inspections are varied over their entire range and visually observed for multiple animated runs to ensure that the aircraft is routed to all appropriate maintenance actions in accordance with its assigned schedule. The outputs reported after each run are also examined to verify that the aircraft had visited each maintenance station for the correct number of times. After the routing logic is tested, both models are run for multiple replications with all sixteen aircraft, and the output reports are examined. The spacer variable method outlined earlier in the methodology is verified by observing the maximum amount of aircraft in each of the queues for each scheduled inspection, which indicates whether or not each aircraft is appropriately spaced to flow through the maintenance cycle properly. Over 50 replications, the maximum amount of aircraft observed in any scheduled

maintenance queue is two, which is reasonable, considering that aircraft schedules are not modified once assigned. Low numbers for the average length of each scheduled maintenance inspection queue are also observed, which indicates that most times, an aircraft routed to a scheduled maintenance inspection begins the process immediately.

Due to time constraints and the amount of abstraction involved in creating the simulation models, a full scale validation is not possible. Partial validation is accomplished by discussing each process captured in the model extensively with subject matter experts. Experienced maintenance and supply personnel currently stationed at the 28th Bomb Wing are able to confirm that the model adequately represents the maintenance cycle of the B-1B. Historical MC and TNMCS rates are also compared to the outputs of the current state model to determine whether or not the model outputs were reasonable. For example, for the month of November 2009, the 735th Supply Chain Management Group reported the rates shown in Table 5.

Table 5. B-1 Rates reported for November 2009

B-1 Rates			
	Overall	Dyess	Ellsworth
TNMCS (Std 8%):	19.1	24.9	11.2
MC (Std 70%):	42.9	42.3	43.6
Stockage Effectiveness:	85.7	85.1	86.6

The report shows that for all B-1Bs at Ellsworth AFB for November 2009, the TNMCS rate was 11.2 percent, and the MC rate was 43.6 percent. Over the past few years, the MC rate has hovered around 40 percent for the B-1B (Malone, 2009). Over 20 replications with a run length of 2000 simulated work days, the average TNMCS rate reported by the current state model is 10.8 percent, with a minimum of 9.6 percent and a

maximum of 11.9 percent. The average MC rate estimate, which reflects the amount of time each aircraft spent in normal operations over the simulation, is 46.4 percent, with a minimum of 44.8 percent and a maximum of 48.1 percent. The TNMCS rate of 11.2 percent is captured in the range of TNMCS rates reported by the model over 20 replications. The MC rate estimates given by the model are slightly higher than the historical MC rate that was reported, which, as discussed earlier, is expected, since there are a significant amount of minor maintenance actions not being explicitly modeled. The current state model therefore appears, at least in terms of the metrics being captured, to be a reasonable approximation of reality.

Since HVM has not been fully implemented for the B-1Bs of the 34th and 37th BS, actual rates to use for model validation do not yet exist. However, the model was created with extensive feedback provided by members of the HVM pilot team at Tinker AFB, OK, who were able to outline how the timing of the maintenance cycle would change under the HVM system.

Summary

A significant amount of the effort in creating useful simulation models for this study was focused on understanding the complex operations of the 28th Bombardment Wing and identifying areas that would be impacted by HVM. Once these areas of impact are determined, a conceptual model of the maintenance process is conceived and a simulation model of the current base maintenance and supply processes is created in ARENA 12. Based on discussions with subject matter experts regarding the changes planned under HVM to the processes being captured in this study, the current state

simulation model is modified to create a separate model reflecting how the processes will operate with the implementation of HVM. Chapter IV covers the analysis involved in comparing the two models to determine some of the impacts that HVM will have on various metrics associated with base maintenance and supply performance.

IV. Analysis and Results

Chapter Overview

This chapter covers the analysis techniques used to compare the performance of the current state model to the HVM model. To gain insight as to how the implementation of HVM will impact the maintenance and supply process of the 28th Bomb Wing, three performance metrics obtained from both models are compared: MC rate estimates, TNMCS rates, and the average total amount of time that an aircraft spends in unscheduled maintenance.

Proponents of HVM claim that aircraft availability rates will increase as a result of reduced total PDM contact days, more frequent PDM inspections, and parts being readily available for maintainers through the use of kitting. The logic behind these claims is that the increase in depot contact frequency will allow for better preventative maintenance to be performed on each airframe, which should reduce the amount of failures that render each aircraft NMC. Additionally, the use of kitting will purportedly increase stockage effectiveness rates, and when an aircraft does require an unscheduled part replacement, lengthy supply delays will be less frequent because the part will likely be available for immediate issue. In terms of the parameters in the simulation models, the intended effects of HVM translate to the following factors: increased time between failures (decreased failure rates), an increase in the percentage of parts that are on hand (stockage effectiveness), and reduced PDM flow days. However, since HVM has not been implemented for the entire B-1B fleet, these intended effects cannot be confirmed or

quantified. Since the exact effect that HVM will have on the model parameters described earlier is unknown, a generalized factorial design is used to determine how each factor previously mentioned impacts the performance of the HVM model.

Through the generalized factorial design, optimal level settings for each factor are determined. The performance of the current state model is therefore compared to two variations of the HVM model: the baseline HVM model, which included the changes to the maintenance process timeline described in Chapter III with no changes to current state aircraft failures and base stockage effectiveness, and a “best case” HVM model, which included the changes to the maintenance process along with the optimal factor settings. The results of the two comparisons are presented.

Simulation Run Setup

All simulation runs, both for the current state model and the two cases of the HVM model, are set up identically in ARENA 12. Currently, a full PDM cycle takes roughly 5 years to complete, since an aircraft is due for PDM every 1800 days (TO 1-B1-B6, 2007). The run lengths are set to 2000 days to capture a full-length PDM cycle under the current maintenance timeline. This way, all 16 aircraft in the current state model undergo PDM at least once. For each of our models we found 20 replications sufficient to provide reasonable confidence interval widths for our performance metrics.

Since accurate maintenance team schedules are not captured in the model, the base units used in the model were days. Each of the 2000 simulated days therefore represents a standard work day for the members of the 28th Bomb Wing. Weekends and

holidays are abstracted out of the model. As a result, all lengths reported by the model reflect the amount of work days that are necessary to complete a process.

Metric Selection

The three metrics that are compared in detail between the two systems are MC rate estimates, TNMCS rates, and the average total time an aircraft spends in unscheduled maintenance.

The most significant metric selected for comparison is the MC rate estimate, which reflects the amount of time that an aircraft spends in normal operations. The main goal of HVM is to improve aircraft availability, which is shown in the model through the MC rate estimate. As discussed earlier, although the MC rate estimates cannot be taken as exact aircraft availability rates due to the minor maintenance actions not captured in the models, it is logical to assume that the time aircraft are spending in normal operations is a reasonable estimate of their availability. Comparisons of the current state and HVM systems focus on the MC rate estimates, which gives a strong indication as to whether or not aircraft availability will improve with the implementation of HVM.

TNMCS is a metric typically reported as a rate used to indicate the strength of the base supply chain. The single TNMCS rate typically reported for a squadron is the average percentage of time that an aircraft is NMC due to a lack of available parts (Milnes, 2009). One of the desired outcomes of HVM is for parts to be more readily available for immediate issue on base through the use of kitting. With improved stockage effectiveness, there will be less supply related delays, since parts will not have to be ordered from alternate sources of supply as frequently, and the squadron TNMCS rate

should drop. TNMCS rates are compared between systems to see if the expected reduction in NMCS time occurs within the HVM model.

As discussed earlier, one of the main reasons for poor B-1B availability rates is that maintainers are being overwhelmed by unscheduled maintenance. A major part of improving B-1B availability with the implementation of HVM will therefore be contingent upon the ability of maintainers to reduce unscheduled maintenance delays under the altered maintenance timelines. The impact that more frequent PDM visits will have on failure rates cannot yet be determined. However, failure rates can be varied in the HVM model to show how possible failure rate improvements under HVM will impact the amount of time that aircraft are spending in unscheduled maintenance. The average total amount of time aircraft are spending in unscheduled maintenance is a convenient way of comparing accumulated unscheduled maintenance times between both systems.

Comparison of Current State Model to the Baseline HVM Model

The baseline HVM model includes the changes discussed in Chapter III. ISOs have been eliminated, and all B-1Bs undergo a 22-day PDM cyclical inspection approximately once every 15 months. However, failure rates and the base stockage effectiveness remained at current state levels.

A paired *t*-test was used to test whether the output metrics differed from the current state model to the baseline HVM model. For each of the 20 replications, the output metrics of the current state model were paired with the output metrics of the baseline HVM model, and the differences were computed. The 20 differences for each metric were then used to compute a 95 percent confidence interval for the difference

between the two systems. If the confidence interval contains zero, then there is no statistically significant difference between the two means at the level of significance used to create the confidence interval (Montgomery, 2009).

The results of the paired *t*-tests are shown in Table 6. For a detailed look at the paired *t*-tests used to compare the current state model to the baseline model reference Appendix B. Note that the numbers shown in Table 6 for each of the metrics represents the mean value achieved after 20 replications.

Table 6. Metric Comparison between the Current State Model and the Baseline HVM Model

	Current State Model	HVM Model	Paired-<i>t</i> Confidence Interval
MC Rate Estimate:	0.464	0.497	(0.025, 0.041)
TNMCS Rate:	0.108	0.116	(0.004, 0.013)
Average Total Unscheduled Maintenance Time:	755.703	835.147	(64.649, 94.239)

Although the paired *t*-test comparisons show that there is a statistically significant difference between the two systems for all three metrics, the MC rate increase is not practically significant. The average MC rate observed for all aircraft over 20 replications differed by only 3.3 percent; the baseline HVM model still shows aircraft availability rates far below the USAF goal of 70 percent. Statistically significant increases in TNMCS rates and average total unscheduled maintenance times are also observed with the baseline HVM model. The altered PDM flow under the HVM system reduces the amount of time that aircraft are spending in scheduled maintenance actions, which results in the slight MC rate increase. However, since current state failure rates are still used, a substantial portion of the extra potential normal operations time incurred by each aircraft

is spent in unscheduled maintenance, which explains the counterintuitive increase in the reported TNMCS rate and average total unscheduled maintenance time with the baseline HVM model. Although the increase in the TNMCS rate is not practically significant, the average total unscheduled maintenance time increases by 65 to 95 days from the current state to the baseline HVM model, which indicates that failures are still preventing acceptable aircraft availability. With current state B-1B failure rates in place for both models, unscheduled maintenance actions are taking up a large portion of time, which explains the poor MC rate estimates observed in both models.

The results of the baseline HVM model comparison show that the reduced PDM flow days introduced with HVM alone will not improve aircraft availability to an acceptable degree. For HVM to be truly effective, aircraft failure rates and base stockage effectiveness will need to improve.

Identification of HVM Impact Factors

Since the effect that HVM will have on aircraft failure rates and base stockage effectiveness cannot be determined with certainty, a 3^3 generalized factorial experiment was created using Design Expert 7 to determine the impact that base stockage effectiveness, aircraft failure rates, and increased maximum PDM times will have on MC rate estimates, TNMCS rates, and unscheduled maintenance times in the HVM model. As discussed earlier, HVM is projected to improve aircraft failure rates and base stockage effectiveness, which is why these factors were selected. Additionally, although PDM visits are planned for 22 days, the increased flow of aircraft to the depot under HVM could cause unforeseen delays due to insufficient manpower and materials. It is

important to gauge how these factors may impact the performance metrics being examined to determine whether or not the implementation of HVM has a reasonable chance of being successful.

In the context of the HVM model, the three factors that were varied in the experiment were the maintenance improvement factor variable, the base stockage effectiveness variable, and the maximum PDM time variable. A summary of all three factors and the specific levels examined in the general factorial design are shown in Table 7. The full factorial design table, along with the verification of the assumptions of ANOVA and model R^2 values, is available in Appendix D.

Table 7. Summary of 3^3 Generalized Factorial Design

Factors	Baseline	L2	L3
Maintenance Improvement Factor	1	2	3
Base Stockage Effectiveness	84.56%	90%	95%
Maximum PDM Time	22 days	44 days	66 days

One replication of a full 3^3 factorial design is used, which calls for a total of 27 separate design points for all possible combinations of the three factors. For each design point, we perform 20 replications with a run length of 2000 work days. The mean values of each response are used as the responses for the factorial design. Since three different responses are examined for each run, our factorial design experiment produced three different models, showing which factors and factor interactions significantly impacted each of the responses. The ANOVA table for the MC rate estimates is shown in Figure 11. Note that interactions are not shown because none of them were statistically significant.

Response	1	MC Rate Estimate			
ANOVA for selected factorial model					
Analysis of variance table [Classical sum of squares - Type II]					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F
Model	0.21	6	0.035	4012.76	< 0.0001
<i>A-Maintenance Improvement Factor</i>	0.20	2	0.10	11590.90	< 0.0001
<i>B-On Hand Percentage</i>	4.416E-003	2	2.208E-003	255.77	< 0.0001
<i>C-Max PDM Times</i>	3.308E-003	2	1.654E-003	191.62	< 0.0001
Residual	1.727E-004	20	8.633E-006		
Cor Total	0.21	26			

Figure 11. ANOVA Table for MC Rate Estimate Factorial Model

The ANOVA shows that while all three factors are significant at any reasonable level of significance due to the low p-values reported, the model is almost completely dominated by the maintenance improvement factor. The contour plot captured in Figure 12 shows the impact of the maintenance improvement factor and base stockage effectiveness on MC rate estimates. Note that the maximum PDM times are set at 22 days for the contour plot.

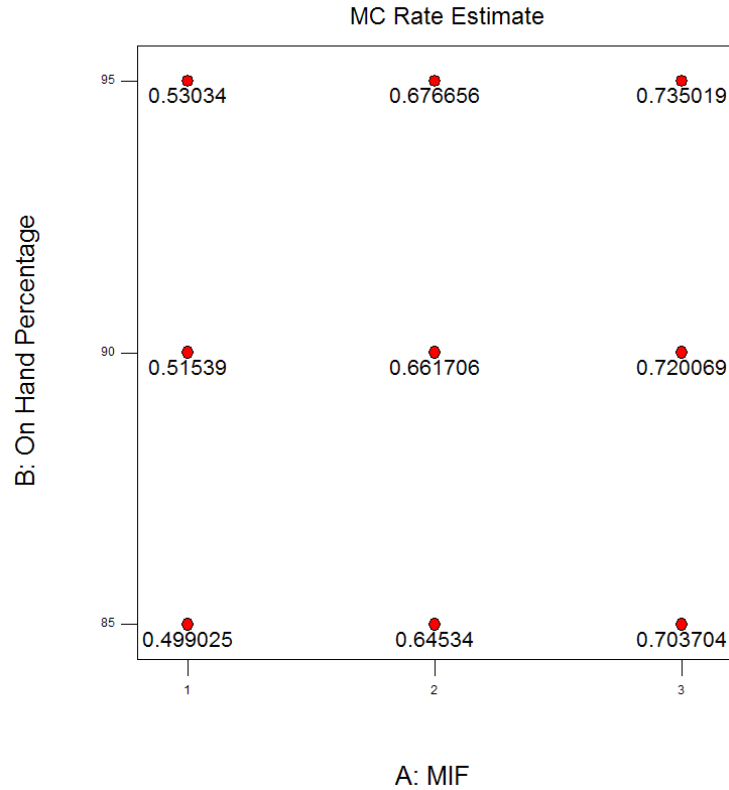


Figure 12. Contour plot depicting the impact of the maintenance improvement factor and base stockage effectiveness on MC rate estimates

As the maintenance improvement factor increases, there is a significant increase in the MC rate estimates. This makes sense, since the current state and baseline HVM systems were overwhelmed by unscheduled maintenance. By increasing the time between failures drawn in the model, all of the aircraft fail less frequently and spend more time in the normal operations process, which increases the MC rate estimate. The MC rate is impacted to a lesser degree by the base stockage effectiveness (shown as on hand percentage in Figures 11 and 12) and the maximum PDM times. As base stockage effectiveness is increased, it becomes more likely that an aircraft in the model will not experience a supply related delay, which can be lengthy. As a result, unscheduled maintenance times are usually accomplished more quickly, and aircraft spend more time

in normal operations. As the maximum PDM time is increased, each aircraft has a chance of experiencing a longer PDM visit, which decreases the amount of time spent in normal operations.

The next response examined was the TNMCS rate. The ANOVA table for the TNMCS rate is shown in Figure 13. Note that interactions that were not statistically significant are not reported.

Response	2	TNMCS			
ANOVA for selected factorial model					
Analysis of variance table [Classical sum of squares - Type II]					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F
Model	0.021	10	2.121E-003	217.35	< 0.0001
<i>A-Maintenance Improvement Factor</i>	5.518E-003	2	2.759E-003	282.79	< 0.0001
<i>B-On Hand Percentage</i>	0.015	2	7.274E-003	745.51	< 0.0001
<i>C-Max PDM Times</i>	6.436E-006	2	3.218E-006	0.33	0.7238
<i>AB</i>	1.134E-003	4	2.835E-004	29.06	< 0.0001
Residual	1.561E-004	16	9.757E-006		
Cor Total	0.021	26			

Figure 13. ANOVA Table for the TNMCS Rate Factorial Model

The base stockage effectiveness is the most significant factor in driving the TNMCS rate. As the stockage effectiveness increases, more aircraft are routed through the immediate issue delay when undergoing unscheduled maintenance, and as a result, NMCS time will not accumulate, and TNMCS rates will drop. Increasing the maintenance improvement factor also reduces the TNMCS rate, since this reduces the frequency of unscheduled maintenance for each aircraft and allows for less NMCS time to accumulate. Maximum PDM times do statistically impact TNMCS rates. The

interaction between base stockage effectiveness and the maintenance improvement factor is also statistically significant, though the reported F value indicates that its effect on TNMCS is not as strong as the individual factors. The contour plot captured in Figure 14 shows the impact that the base stockage effectiveness and maintenance improvement factor have on TNMCS rates. The strength of the interaction between the maintenance improvement factor and the base stockage effectiveness is shown in Figure 15. Note that the maximum PDM times are set at 22 days for the contour and interaction plots.

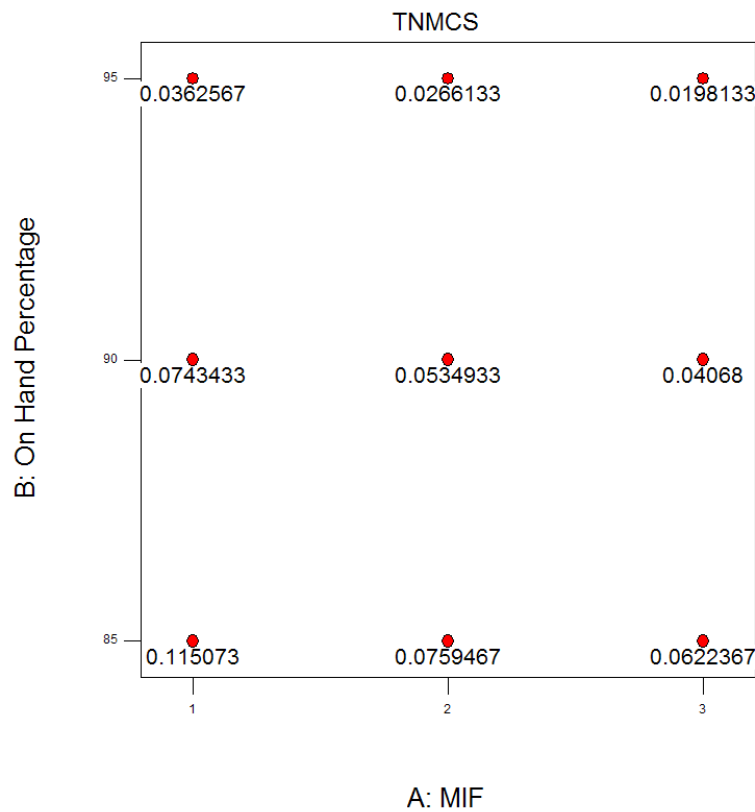


Figure 14. Contour plot depicting the impact of the maintenance improvement factor and base stockage effectiveness on TNMCS rates

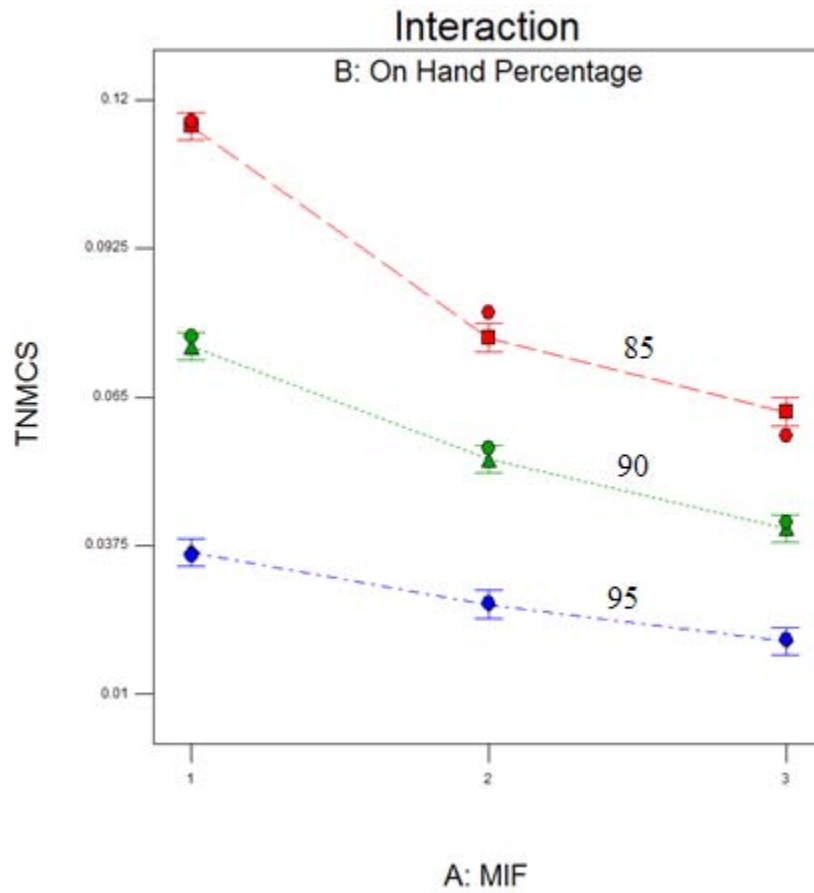


Figure 15. TNMCS rate interaction plot of the maintenance improvement factor and base stockage effectiveness

The last response examined is the average amount of time that each aircraft spends in unscheduled maintenance throughout the entire simulation. The ANOVA table for the average total time in unscheduled maintenance is shown in Figure 16.

Response	3	Average Total UM Days			
ANOVA for selected factorial model					
Analysis of variance table [Classical sum of squares - Type II]					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F
Model	8.521E+005	6	1.420E+005	4032.38	< 0.0001
<i>A-Maintenance Improvement Factor</i>	8.305E+005	2	4.152E+005	11789.97	< 0.0001
<i>B-On Hand Percentage</i>	18050.83	2	9025.41	256.27	< 0.0001
<i>C-Max PDM Times</i>	3586.29	2	1793.14	50.91	< 0.0001
Residual	704.38	20	35.22		
Cor Total	8.528E+005	26			

Figure 16. ANOVA Table for the Average Total Unscheduled Maintenance Days Factorial Model

The driving factor for the amount of unscheduled maintenance time incurred by each aircraft is the maintenance improvement factor, although the base stockage effectiveness and maximum PDM times still have some impact. The contour plot captured in Figure 17 shows the impact that the maintenance improvement factor and base stockage effectiveness have on the average total unscheduled maintenance days. Note that the maximum PDM times are set at 22 days for the contour plot.

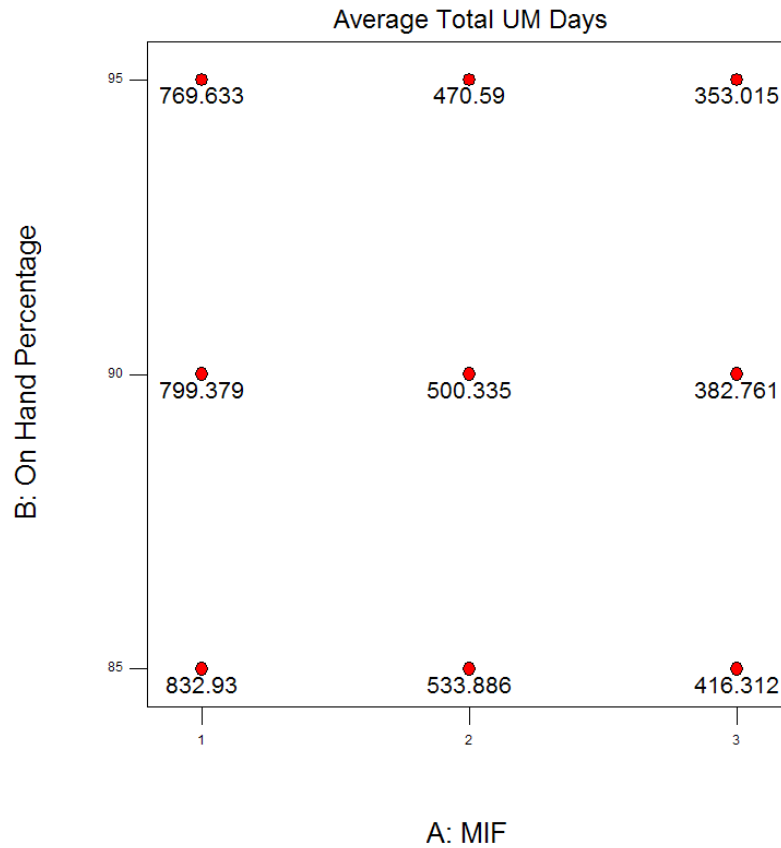


Figure 17. Contour plot depicting the impact of the maintenance improvement factor and base stockage effectiveness on the average total unscheduled maintenance days

The factor that had the most impact on MC rate estimates and accumulated unscheduled maintenance time was the maintenance improvement factor, which makes sense, considering that the baseline HVM model is overwhelmed by unscheduled maintenance. TNMCS rates are most significantly impacted by base stockage effectiveness, although the maintenance improvement factor still plays a significant role.

Comparison of Current State Model to the Best Case HVM Model

Our “Best Case” HVM model is configured based on the regression models created for each of the three responses examined in the generalized factorial design. MC rate estimates are maximized, while TNMCS rates and average total unscheduled maintenance times are minimized with the following levels for each of the three factors: the maintenance improvement factor is set to 3, base stockage effectiveness is set to 95 percent, and maximum PDM times are set at 22 days. The best case HVM model therefore assumes that time between failures improves by 300 percent, base stockage effectiveness increases by over 10 percent, and no delays in scheduled flow days for any aircraft that undergoes PDM.

Once the best case HVM model was configured, it was compared to the current state model with the same method used to compare the baseline HVM model to the current state model. The results of the paired *t*-test comparisons are shown in Table 8. For a detailed look at the paired *t*-tests used to compare the current state model to the best case HVM model reference Appendix C. Note that the numbers shown in Table 8 for each of the metrics represents the mean value achieved after 20 replications.

Table 8. Metric Comparison between the Current State Model and the Best Case HVM Model

	Current State Model	HVM Model	Paired- <i>t</i> Confidence Interval
MC Rate Estimate:	0.464149	0.7361475	(0.265, 0.279)
TNMCS Rate:	0.1075065	0.020029	(-0.091, -0.084)
Average Total Unscheduled Maintenance Time:	755.703	349.58	(-418.672, -393.574)

These results show that there is a significant improvement in all three performance metrics with the best case HVM model. MC rate estimates are improved by

nearly 30 percent, while TNMCS rates drop from almost 11 percent to around 2 percent and the average total unscheduled maintenance days incurred by each B-1B in the model drops by over 50 percent from the current state model. Clearly, if failure rates and stockage effectiveness improve with the implementation of HVM and depot maintainers are able to sustain the planned 22 day PDM flow times, HVM will significantly improve aircraft availability, and NMCS times will be reduced.

Summary

Once the proper simulation run setup and output metrics are determined, the current state model is compared to the baseline HVM model. The comparison showed that the altered PDM flow alone will not improve aircraft availability to an acceptable level. A generalized factorial design is then used to reveal how aircraft availability, TNMCS rates, and accumulated unscheduled maintenance times are impacted by varying factors in the baseline HVM model that could be improved once HVM is implemented. The designed experiment showed that the driving force in improving the output metrics of the baseline HVM model would be improving B-1B failure rates. Based on the results of the designed experiment, the baseline HVM model is configured for optimal performance, and this “best case” HVM model was compared to the current state model. The best case HVM model featured substantially improved aircraft availability rates along with a significant reduction in TNMCS rates and accumulated unscheduled maintenance days. This shows that if the implementation of HVM brings the improvements to base operations that have been planned, it definitely has the potential to bring B-1B aircraft availability to an acceptable level. However, the improvements built

into the best case HVM model are by no means guaranteed. Chapter V discusses the implications of the analysis presented here and some final recommendations regarding the implementation of HVM for the B-1B.

V. Conclusions and Recommendations

Chapter Overview

This chapter discusses the implications of the analysis results presented in Chapter IV. The feasibility of the best case HVM model is examined, and input from experienced B-1B maintenance personnel is incorporated. The chapter concludes with final recommendations for the implementation of HVM for the B-1B.

Analysis Implications

The best case HVM model featured a significantly improved MC rate estimate, TNMCS rate, and average total unscheduled maintenance days over the current state model. If B-1B failure rates and base stockage effectiveness improves to the levels examined in this study with the implementation of HVM, aircraft availability and TNMCS rates will likely change to meet USAF standards.

However, the analysis showed that the baseline HVM model did not offer adequate levels of improvement in aircraft availability and TNMCS rates. Therefore, the reduced PDM flow days alone will not fix the poor MC rates that are currently plaguing the B-1B fleet. The benefits of the best case HVM model are almost entirely reliant on the increased base stockage effectiveness and, most importantly, the improvement in aircraft failure rates introduced with the maintenance improvement factor. An examination of Table 6 shows that with current state aircraft failure rates, the B-1Bs in both models are averaging relatively large amounts of time in unscheduled maintenance,

even with the reduced PDM flow days under HVM. Unfortunately, determining whether or not the improvements to base operations built into the best case HVM model will occur is beyond the scope of this research. Clearly, HVM has the potential to offer significant improvements, but it cannot be definitively concluded that the implementation of HVM will improve B-1B availability.

Feasibility of the Best Case HVM Model

The best case HVM model is configured with the following settings: the maintenance improvement factor was set at 3, the base stockage effectiveness was set at 95 percent, and the maximum PDM flow days were capped at 22 days. Configuring the HVM model in this fashion requires lofty assumptions about the improvements that the implementation of HVM will bring to base operations.

The generalized factorial design showed that the maintenance improvement variable was the most significant factor in the HVM model for impacting MC rates and accumulated days in unscheduled maintenance per aircraft. Setting the maintenance improvement factor to 3 triples all of the times to the next failure that are drawn in the simulation model. In other words, aircraft failure rates were improved by 300 percent over the current state aircraft failures in the best case HVM model. However, an improvement of this magnitude seems extremely unlikely, even with the increased depot contact under the HVM system. Will the increased focus on preventative maintenance under HVM improve B-1B failure rates to the magnitudes examined in this study? Even the most experienced B-1B maintenance personnel cannot make this prediction with

certainty. Considering that the B-1B fleet is continuing to age, it is entirely possible that aircraft failure rates may actually become worse than they are now.

The TNMCS rate model output is most significantly impacted by the base stockage effectiveness, which was increased by over 10 percent in the best case HVM model compared to the current stockage effectiveness reported by the 28th Logistics Readiness Squadron at Ellsworth AFB. The best case HVM model showcased an average TNMCS rate of about 2 percent over 20 replications, which is stellar according to USAF standards. However, this assumes that the implementation of kitting with HVM will increase base stockage effectiveness to 95 percent. Discussions with base maintenance subject matter experts has revealed a universal skepticism regarding the supposed effectiveness of kitting being promoted by the HVM pilot team at Tinker AFB. The most glaring flaw in the practicality of kitting implementation on base is that it will require additional personnel to provide the necessary logistical support to track down and preemptively order necessary parts (Pedersen, 2009). Considering that the maintenance squadrons of the 28th Bomb Wing are already short on personnel, acquiring the support necessary for successful implementation of kitting will probably not happen. Furthermore, the implementation of kitting will drive up maintenance costs, since additional parts will need to be stocked on base (Pedersen, 2009). The future of kitting, at least at the base level, appears to be quite bleak.

The maximum PDM flow days were set to 22 in the best case HVM model, which assumes that there will be no delays to the timelines outlined by the HVM pilot team for any B-1B undergoing PDM. Considering the current state of B-1B maintenance, this too

seems unlikely, especially considering that with the implementation of HVM, there will be an increased number of B-1Bs being sent to the depot for PDM.

Future Research and Conclusions

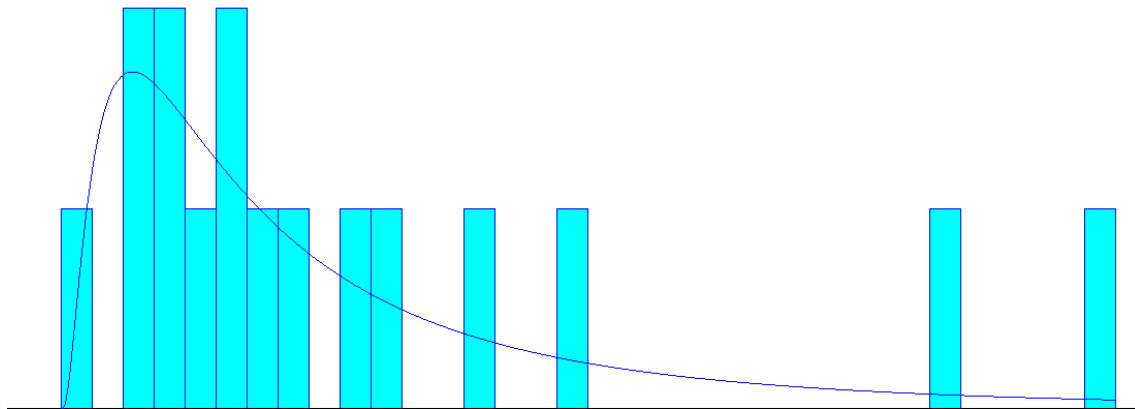
To make a more accurate determination as to whether or not HVM will be a sustainable maintenance program that can improve B-1B availability, the impact that HVM will have on B-1B aircraft performance and various base operations needs to be determined with greater precision. The levels of improvement to B-1B failure rates and base stockage effectiveness examined in this study were based loosely on discussions with members of the HVM pilot team and experienced maintenance and supply personnel of the 28th Bomb Wing. To obtain realistic results from the models created in this study, realistic parameters must be determined. Once more data becomes available on the impact that HVM is having on the B-1B fleet, the levels examined in this model can be calibrated appropriately.

The simulation study conducted here, as explained in the research scope, was intended to be a first-cut, high-level effort at examining the impact that HVM will likely have on base operations. The models created in this study can be augmented to include more extensive pieces of base operations, such as capturing actual sortie generation or additional supply activities, which could provide more fidelity in the MC and TNMCS rates being reported.

Appendix A. Fitted Process Distributions used in the Simulation Models

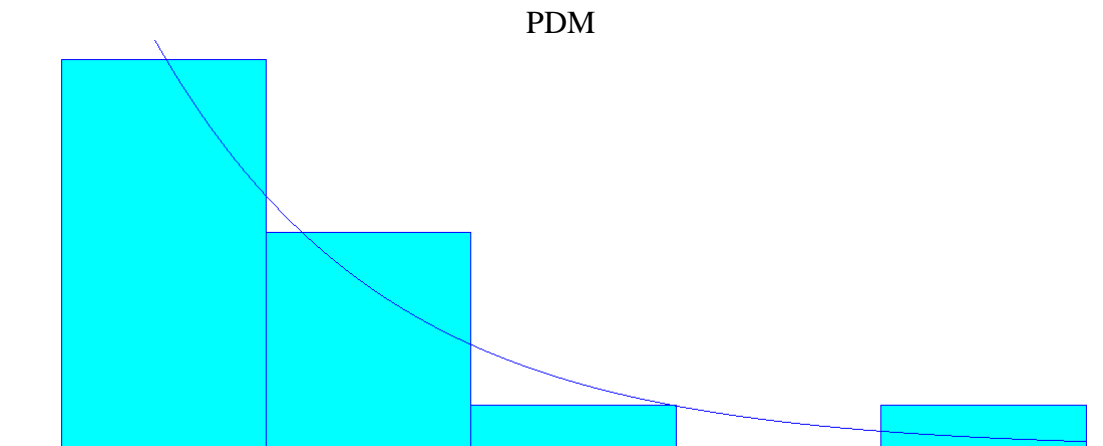
Scheduled Inspection Distributions:

ISO



Distribution Summary	
Distribution:	Lognormal
Expression:	$12.5 + \text{LOGN}(10.3, 13.5)$
Square Error:	0.031566
Data Summary	
Number of Data Points	= 16
Min Data Value	= 13
Max Data Value	= 46
Sample Mean	= 22.1
Sample Std Dev	= 9.39
Histogram Summary	
Histogram Range	= 12.5 to 46.5
Number of Intervals	= 34

Figure 18. Distribution Summary for Isochronal Inspections



Distribution Summary	
Distribution:	Exponential
Expression:	116 + EXPO(44)
Square Error:	0.010736
Chi Square Test	
Number of intervals	= 3
Degrees of freedom	= 1
Test Statistic	= 0.906
Corresponding p-value	= 0.37
Kolmogorov-Smirnov Test	
Test Statistic	= 0.132
Corresponding p-value	> 0.15
Data Summary	
Number of Data Points	= 32
Min Data Value	= 116
Max Data Value	= 311
Sample Mean	= 160
Sample Std Dev	= 43.2
Histogram Summary	
Histogram Range	= 116 to 311
Number of Intervals	= 5

Figure 19. Distribution Summary for PDM

Unscheduled Maintenance Distributions:

Time to next Aircraft Failure (TNF)

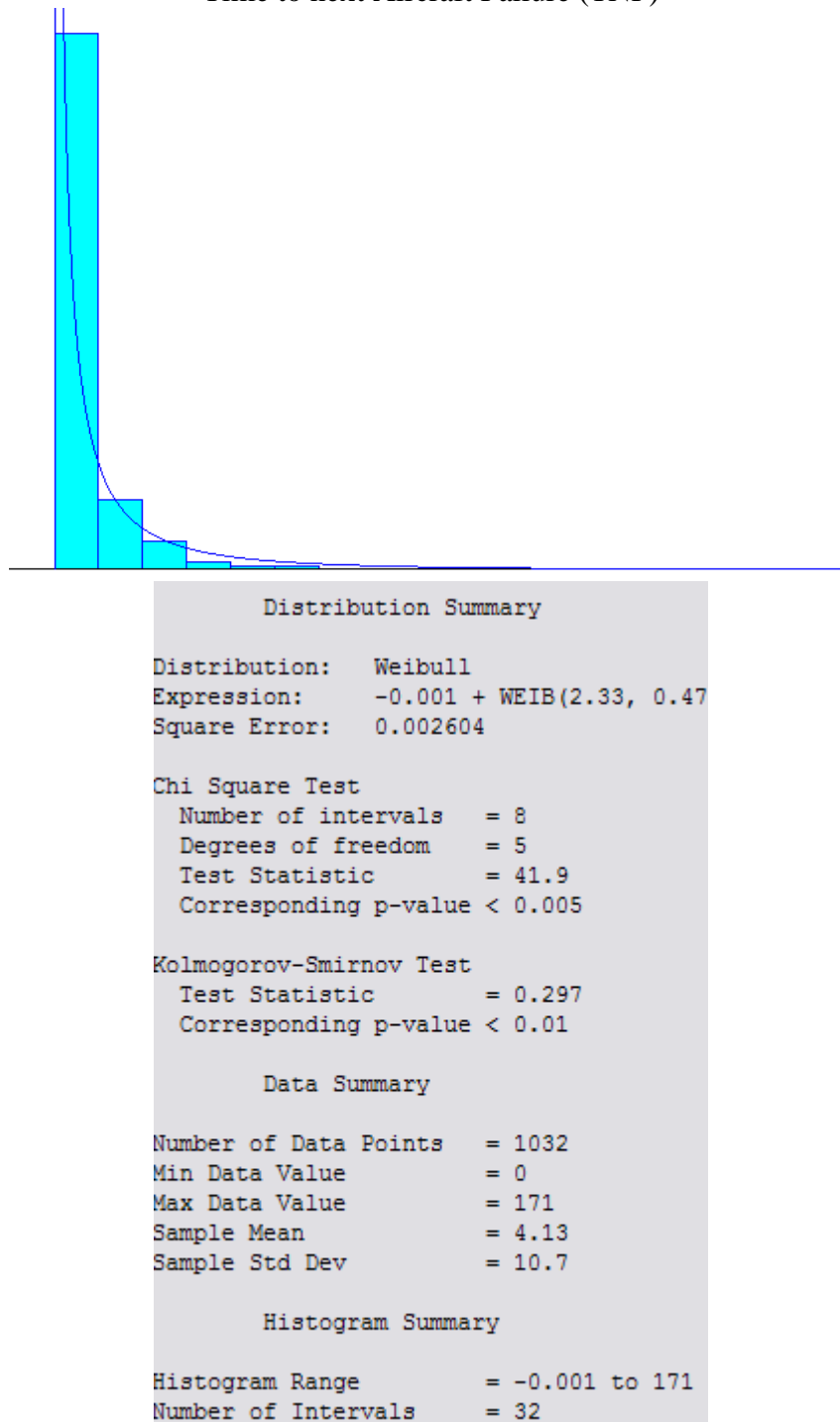


Figure 20. Distribution Summary for Time to next Aircraft Failure

Unscheduled Maintenance Times

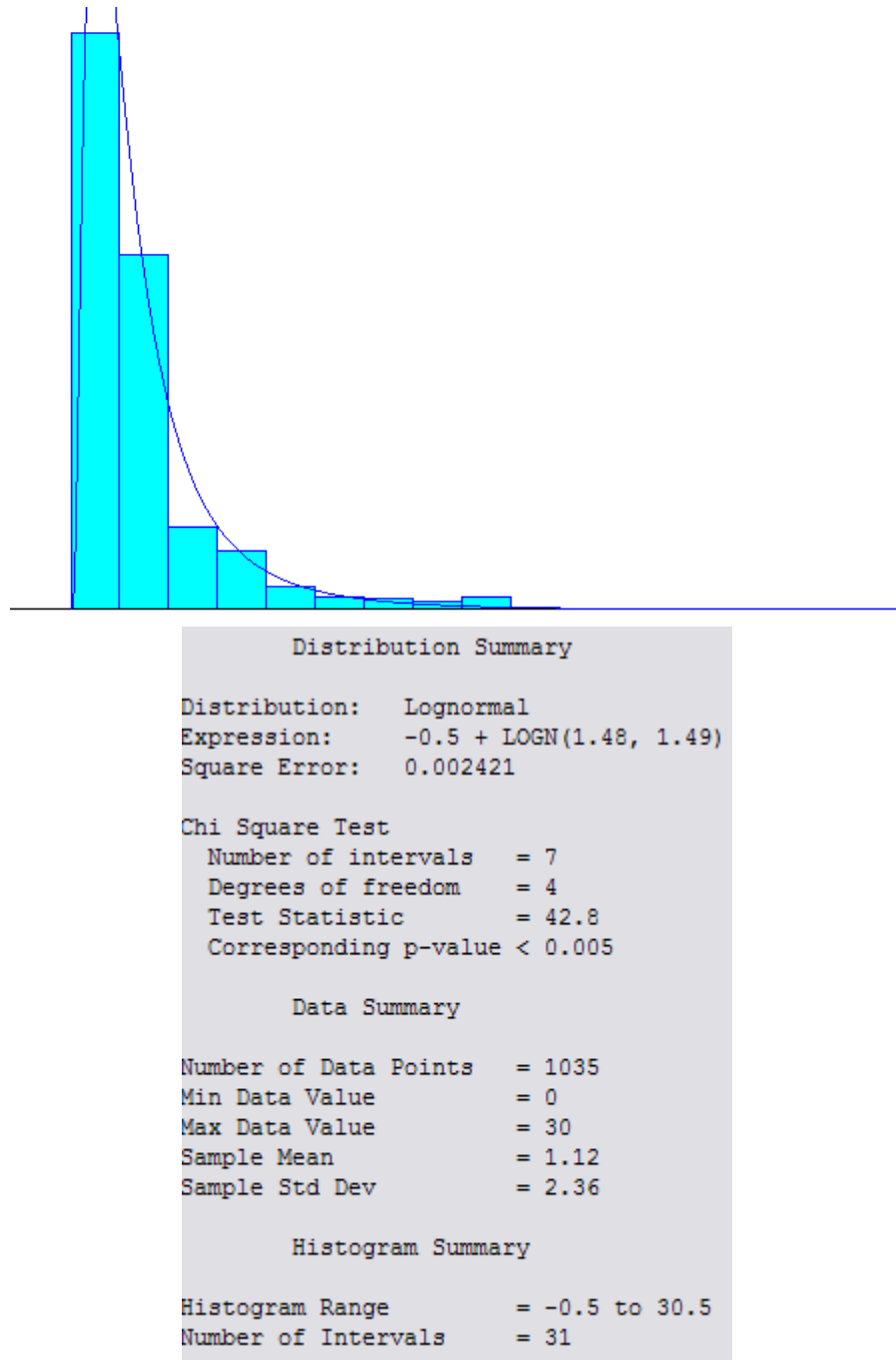


Figure 21. Distribution Summary for Unscheduled Maintenance Times

Supply Delay Distributions:

DLA

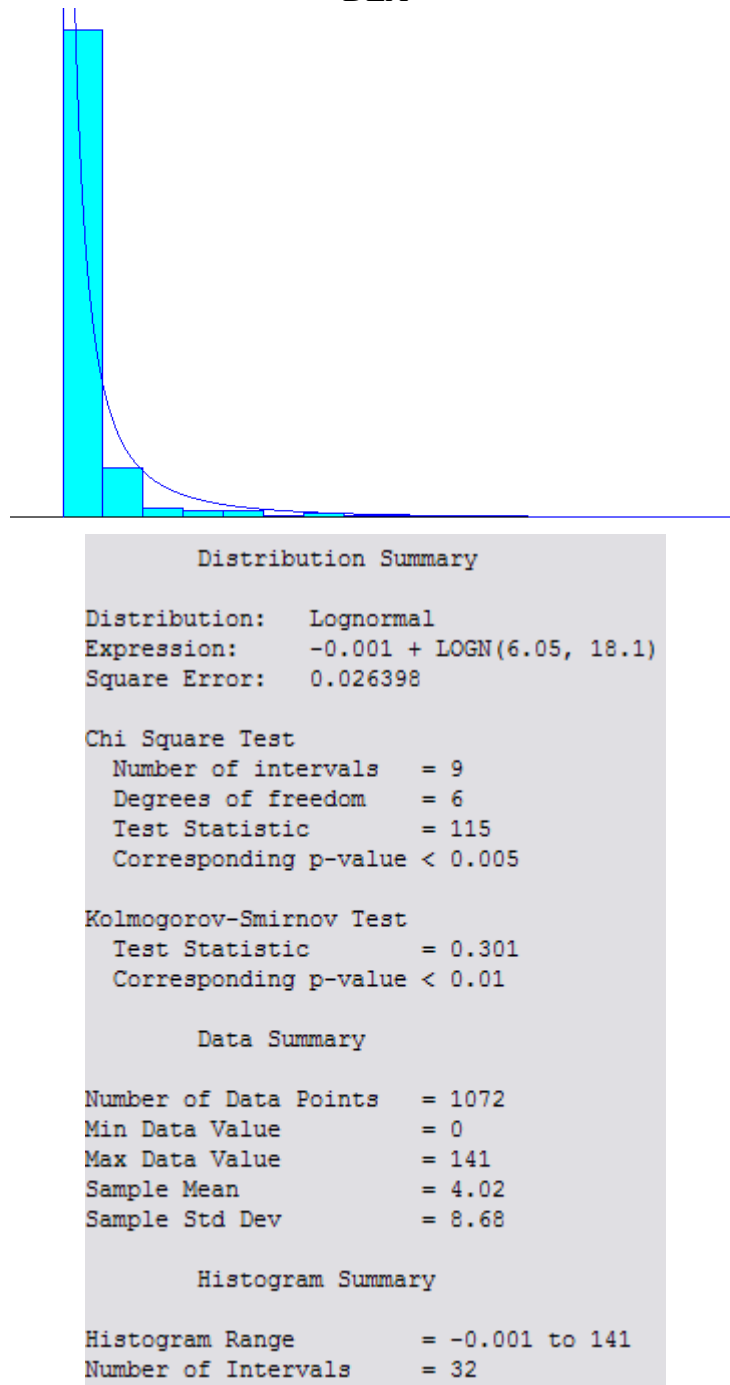


Figure 22. Distribution Summary for DLA Supply Delay

AFMC Depot

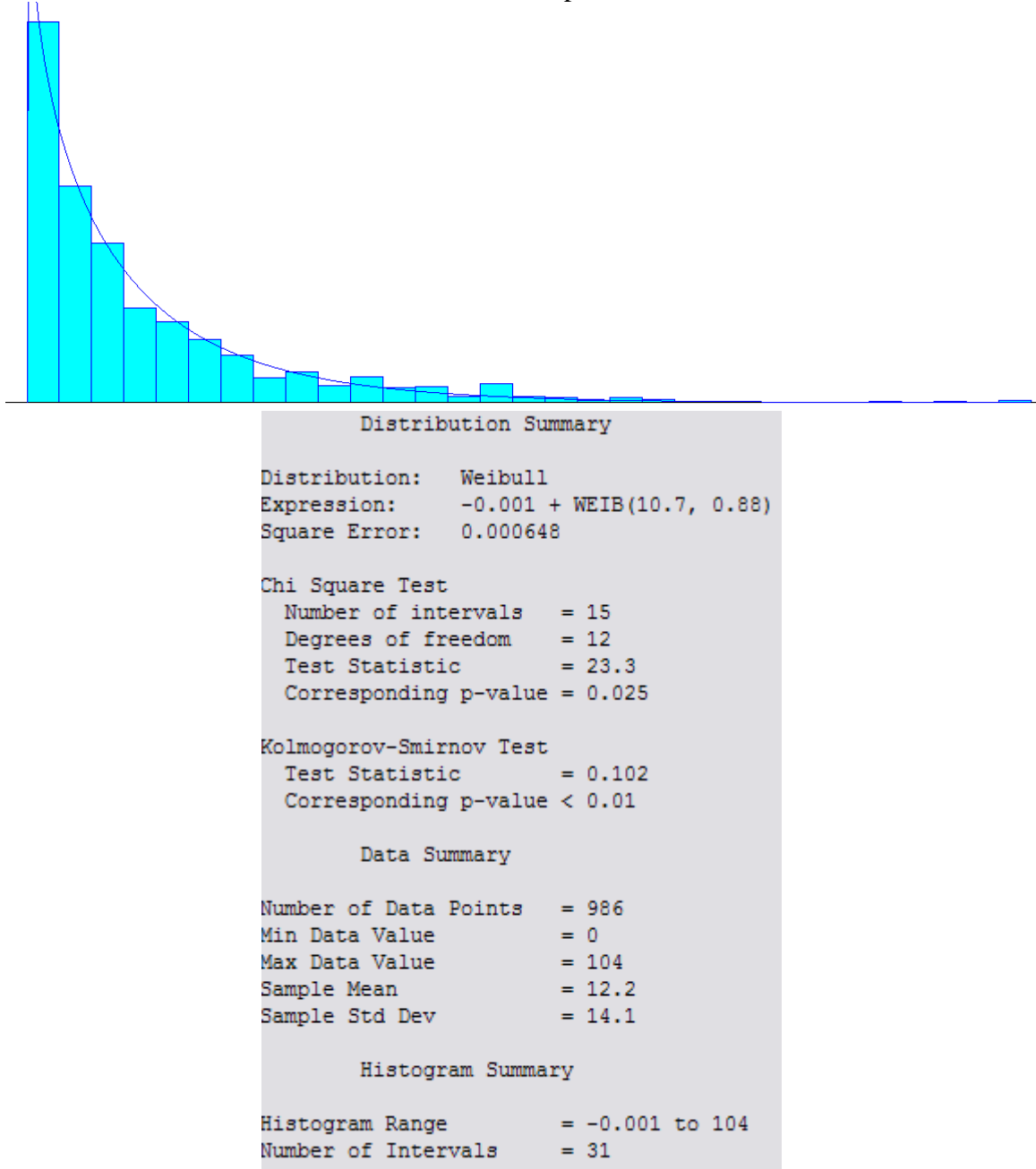


Figure 23. Distribution Summary for AFMC Depot Supply Delay

Lateral Supply

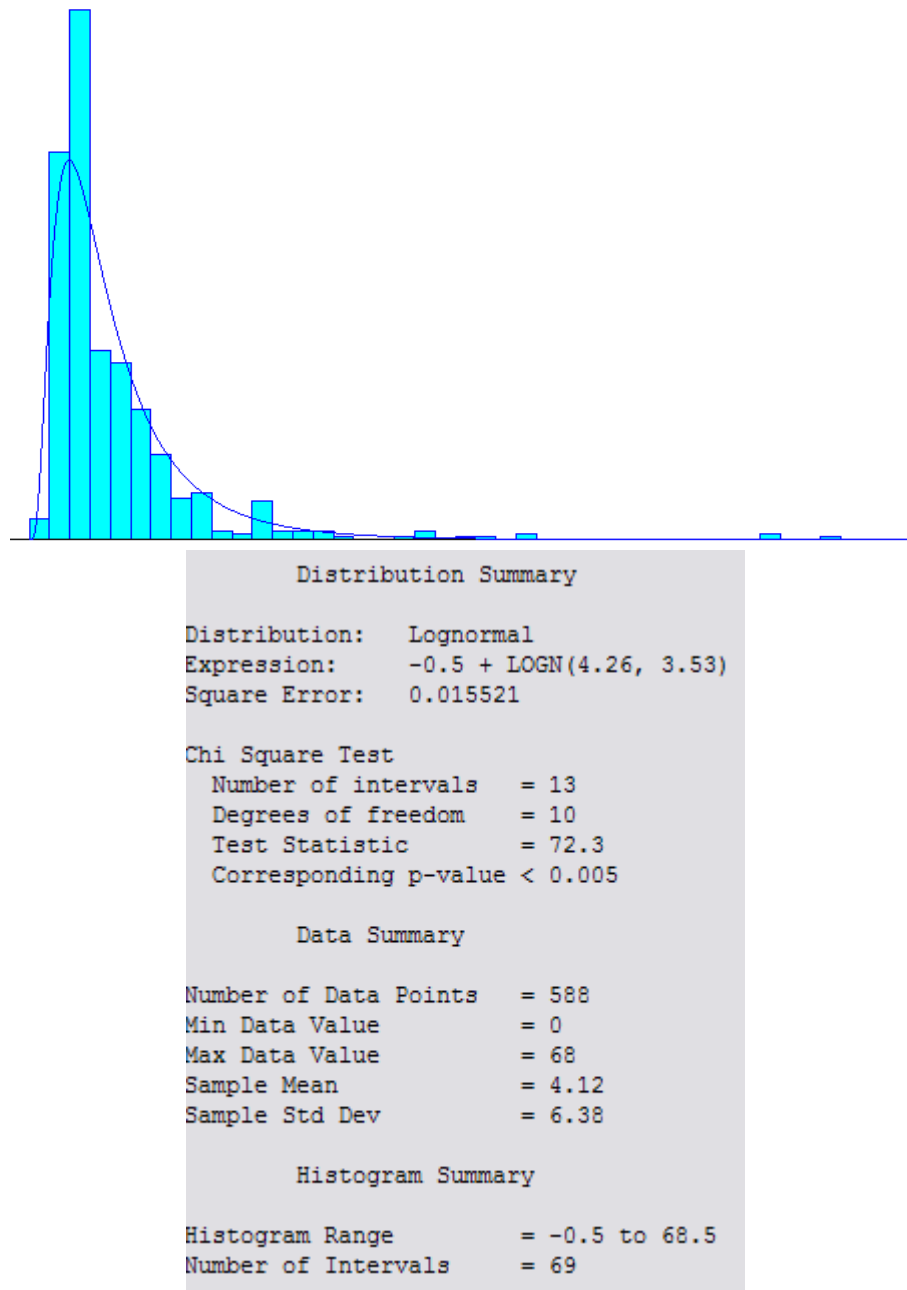


Figure 24. Distribution Summary for Lateral Supply Delay

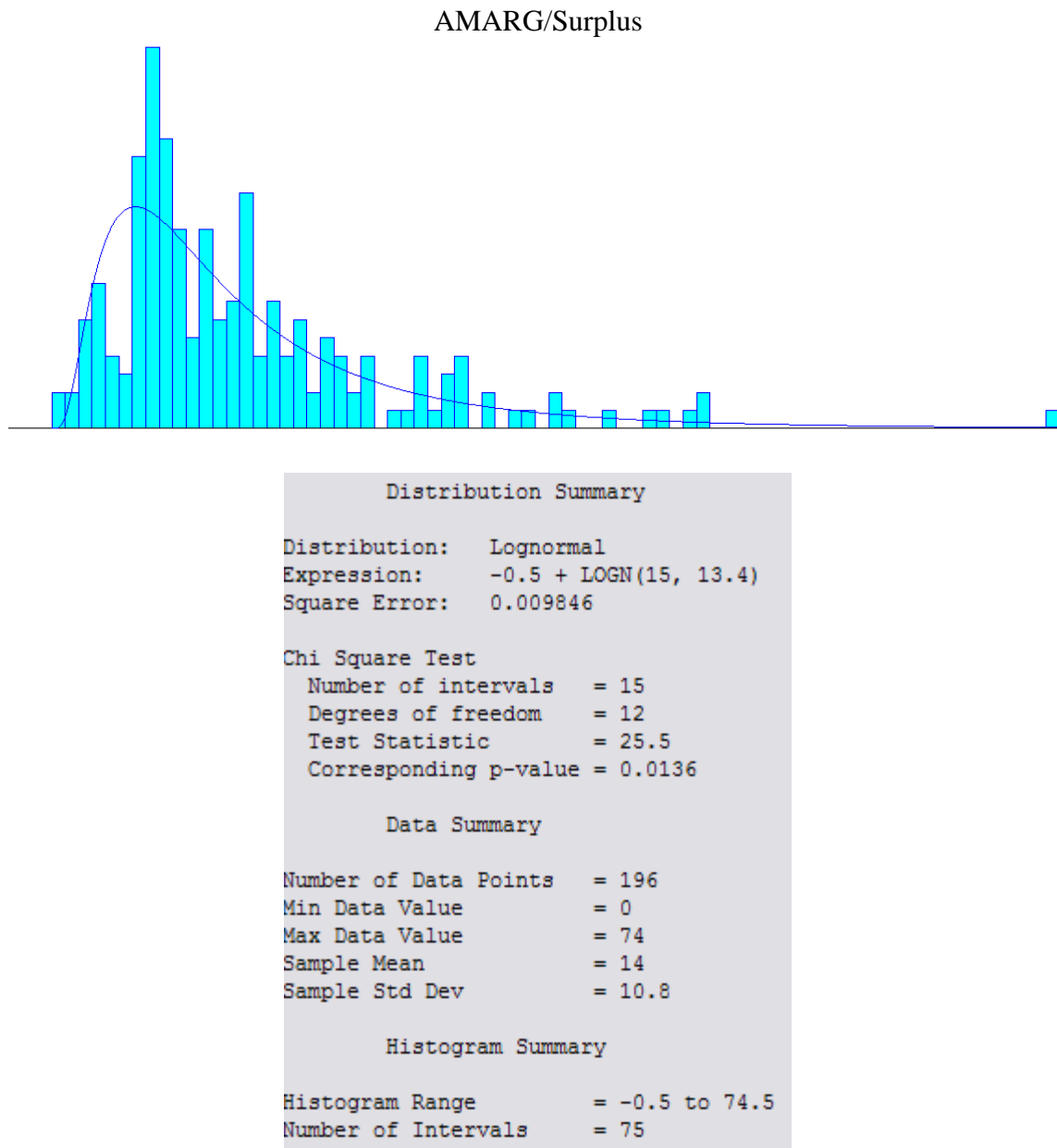


Figure 25. Distribution Summary for AMARG/Surplus Supply Delay

MRSP Kit

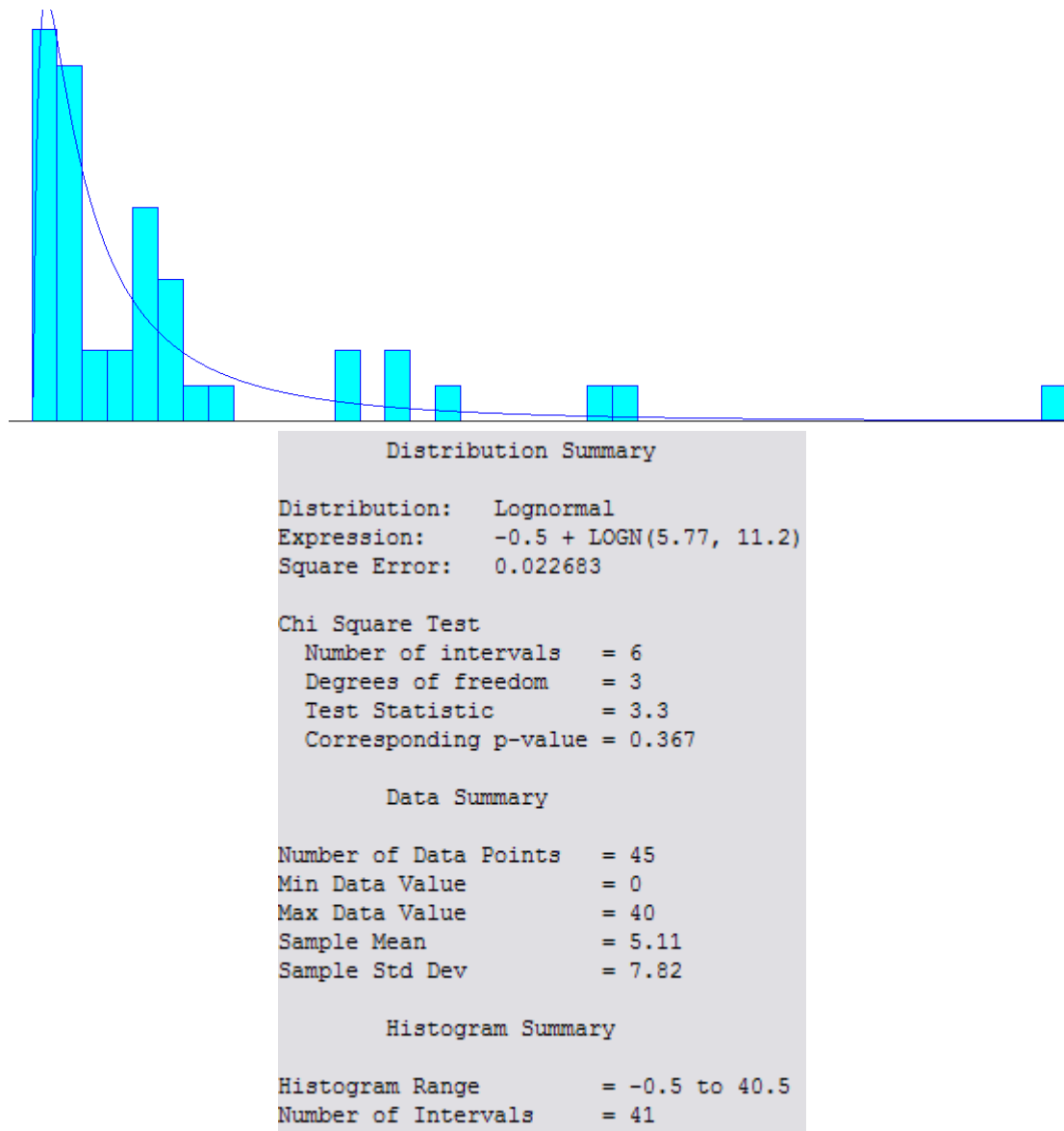


Figure 26. Distribution Summary for MRSP Kit Supply Delay

OTHER

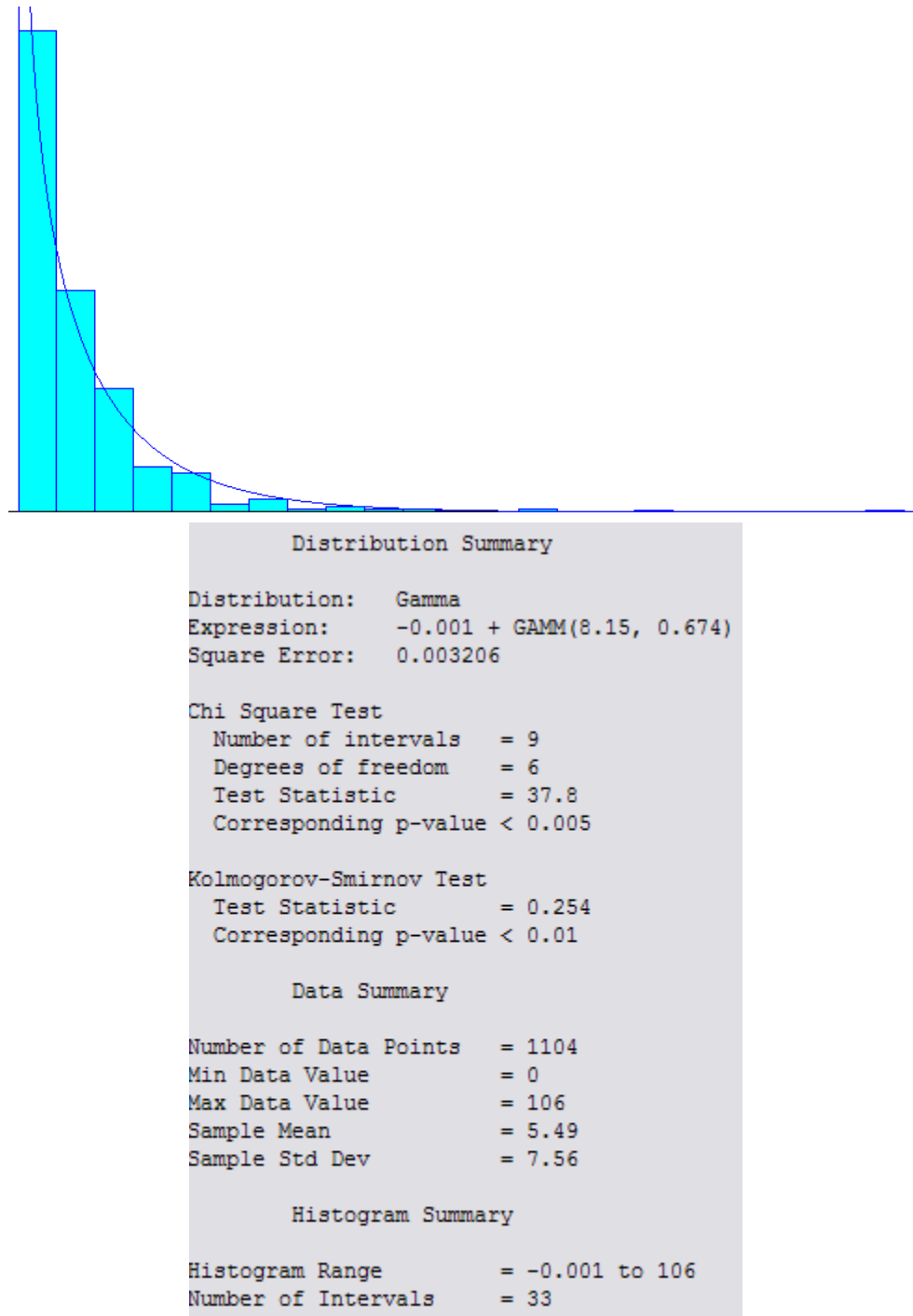


Figure 27. Distribution Summary for Aggregated Alternate Sources Supply Delay

Appendix B. Paired *t*-Test Comparison of the Current State Model to the Baseline HVM Model

Table 9. MC Rate Estimate Comparison of the Current State Model to the Baseline HVM Model

Replication	Current State Model	Baseline HVM Model	Difference
1	0.47991	0.49541	0.0155
2	0.47009	0.48028	0.01019
3	0.4635	0.50349	0.03999
4	0.46122	0.51029	0.04907
5	0.46772	0.50216	0.03444
6	0.45725	0.48206	0.02481
7	0.46159	0.49944	0.03785
8	0.4605	0.50213	0.04163
9	0.47566	0.4955	0.01984
10	0.45531	0.50256	0.04725
11	0.47672	0.49813	0.02141
12	0.44813	0.4787	0.03057
13	0.47119	0.51666	0.04547
14	0.47153	0.47837	0.00684
15	0.48047	0.50084	0.02037
16	0.46203	0.52025	0.05822
17	0.45772	0.50006	0.04234
18	0.45284	0.49244	0.0396
19	0.46163	0.48425	0.02262
20	0.44797	0.49688	0.04891
		Zmean:	0.032846
		Zstddev:	0.0144074
	tcrit:	CI lower:	0.0250065
	2.433440208	CI upper:	0.0406855
	mean CSM:	0.464149	
	mean HVM:	0.496995	

Table 10. TNMCS Rate Comparison of the Current State Model to the Baseline HVM Model

Replication	Current State Model	Baseline HVM Model	Difference
1	0.10006	0.10894	0.00888
2	0.10484	0.12044	0.0156
3	0.10828	0.104	-0.00428
4	0.10747	0.11112	0.00365
5	0.10541	0.11306	0.00765
6	0.11237	0.11031	-0.00206
7	0.104	0.10862	0.00462
8	0.11956	0.12563	0.00607
9	0.09756	0.11881	0.02125
10	0.10638	0.12219	0.01581
11	0.10419	0.12453	0.02034
12	0.11269	0.12328	0.01059
13	0.10094	0.11522	0.01428
14	0.11541	0.13269	0.01728
15	0.09563	0.11975	0.02412
16	0.10237	0.11028	0.00791
17	0.11781	0.11281	-0.005
18	0.11194	0.11566	0.00372
19	0.11156	0.11791	0.00635
20	0.11166	0.10416	-0.0075
		Zmean:	0.008464
		Zstddev:	0.009037
	tcrit:	CI lower:	0.0035467
	2.433440208	CI upper:	0.0133813
	mean CSM:	0.1075065	
	mean HVM:	0.1159705	

Table 11. Average Total Unscheduled Maintenance Days Comparison of the Current State Model to the Baseline HVM Model

Replication	Current State Model	Baseline HVM Model	Difference
1	734.75	840	105.25
2	757.81	866	108.19
3	764.31	821.81	57.5
4	762.68	812.31	49.63
5	752.5	827.81	75.31
6	780.5	863.68	83.18
7	767.87	832.29	64.42
8	776.25	820.12	43.87
9	732.87	838.37	105.5
10	783	821.31	38.31
11	739.93	831.49	91.56
12	781.75	869.15	87.4
13	732.12	799.06	66.94
14	734.18	871.93	137.75
15	713.68	833.07	119.39
16	742	786.18	44.18
17	772	829.25	57.25
18	769.12	845.18	76.06
19	767.18	853.12	85.94
20	749.56	840.81	91.25
		Zmean:	79.444
		Zstddev:	27.190137
	tcrit:	CI lower:	64.648928
	2.433440208	CI upper:	94.239072
	Mean CSM:	755.703	
	Mean HVM:	835.147	

Appendix C. Paired *t*-Test Comparison of the Current State Model to the Best Case HVM Model

Table 12. MC Rate Estimate Comparison of the Current State Model to the Best Case HVM Model

Replication	Current State Model	Best-Case HVM Model	Difference
1	0.47991	0.73716	0.25725
2	0.47009	0.72258	0.25249
3	0.4635	0.71978	0.25628
4	0.46122	0.72891	0.26769
5	0.46772	0.73004	0.26232
6	0.45725	0.73272	0.27547
7	0.46159	0.7436	0.28201
8	0.4605	0.743	0.2825
9	0.47566	0.73552	0.25986
10	0.45531	0.73545	0.28014
11	0.47672	0.73895	0.26223
12	0.44813	0.73003	0.2819
13	0.47119	0.73219	0.261
14	0.47153	0.73834	0.26681
15	0.48047	0.74369	0.26322
16	0.46203	0.74328	0.28125
17	0.45772	0.74397	0.28625
18	0.45284	0.73863	0.28579
19	0.46163	0.74302	0.28139
20	0.44797	0.74209	0.29412
		Zmean:	0.2719985
		Zstddev:	0.0122871
	tcrit:	CI lower:	0.2653127
	2.433440208	CI upper:	0.2786843
	mean CSM:	0.464149	
	mean HVM:	0.7361475	

Table 13. TNMCS Rate Comparison of the Current State Model to the Best Case HVM Model

Replication	Current State Model	Best-Case HVM Model	Difference
1	0.10006	0.01725	-0.08281
2	0.10484	0.01737	-0.08747
3	0.10828	0.023	-0.08528
4	0.10747	0.02028	-0.08719
5	0.10541	0.02022	-0.08519
6	0.11237	0.0185	-0.09387
7	0.104	0.01819	-0.08581
8	0.11956	0.01581	-0.10375
9	0.09756	0.02125	-0.07631
10	0.10638	0.02269	-0.08369
11	0.10419	0.02053	-0.08366
12	0.11269	0.02269	-0.09
13	0.10094	0.02166	-0.07928
14	0.11541	0.02263	-0.09278
15	0.09563	0.02069	-0.07494
16	0.10237	0.017	-0.08537
17	0.11781	0.01966	-0.09815
18	0.11194	0.01897	-0.09297
19	0.11156	0.01944	-0.09212
20	0.11166	0.02275	-0.08891
		Zmean:	-0.0874775
		Zstddev:	0.0069773
	tcrit:	CI lower:	-0.0912741
	2.433440208	CI upper:	-0.0836809
	mean CSM:	0.1075065	
	mean HVM:	0.020029	

Table 14. Average Total Unscheduled Maintenance Days Comparison of the Current State Model to the Best Case HVM Model

Replication	Current State Model	Best-Case HVM Model	Difference
1	734.75	345.37	-389.38
2	757.81	368.9	-388.91
3	764.31	375.31	-389
4	762.68	361.98	-400.7
5	752.5	360.98	-391.52
6	780.5	357.08	-423.42
7	767.87	332.11	-435.76
8	776.25	337.75	-438.5
9	732.87	354.42	-378.45
10	783	344.57	-438.43
11	739.93	348.4	-391.53
12	781.75	358.56	-423.19
13	732.12	361.5	-370.62
14	734.18	346.56	-387.62
15	713.68	342	-371.68
16	742	335.62	-406.38
17	772	340.37	-431.63
18	769.12	345.13	-423.99
19	767.18	334.93	-432.25
20	749.56	340.06	-409.5
		Zmean:	-406.123
		Zstddev:	23.061843
	tcrit:	CI lower:	-418.67173
	2.433440208	CI upper:	-393.57427
	Mean CSM:	755.703	
	Mean HVM:	349.58	

Appendix D. HVM Model 3³ Generalized Factorial Design

Table 15. HVM Model 3³ Generalized Factorial Design Table

Std	Run	Factor 1 A:Maintenance Improvement Factor	Factor 2 B:On Hand Percentage	Factor 3 C:Max PDM Times Days	Response 1 MC Rate Estimate	Response 2 TNMCS	Response 3 Average Total UM Days
1	2	1	85	22	0.49699	0.11597	835.15
2	27	2	85	22	0.64458	0.08068	535.74
3	23	3	85	22	0.70836	0.05775	411
4	12	1	90	22	0.51352	0.0761	802.79
5	5	2	90	22	0.65959	0.05554	506.51
6	17	3	90	22	0.72318	0.04172	372.78
7	19	1	95	22	0.52561	0.0357	778.61
8	6	2	95	22	0.67927	0.0269	466.68
9	21	3	95	22	0.73615	0.02003	349.58
10	24	1	85	44	0.48489	0.11532	817.53
11	9	2	85	44	0.63381	0.06806	509.21
12	1	3	85	44	0.6899	0.06697	407.22
13	20	1	90	44	0.50036	0.07481	787.4
14	14	2	90	44	0.64609	0.05373	490.48
15	18	3	90	44	0.7043	0.04092	370.58
16	3	1	95	44	0.51644	0.036	755.02
17	25	2	95	44	0.66365	0.02675	454.3
18	13	3	95	44	0.71922	0.02053	341.15
19	4	1	85	66	0.4715	0.11393	806.37
20	15	2	85	66	0.61553	0.0791	511.04
21	22	3	85	66	0.67448	0.06199	389.45
22	8	1	90	66	0.49578	0.07212	758.97
23	26	2	90	66	0.63402	0.05121	471.83
24	7	3	90	66	0.69049	0.0394	359.41
25	10	1	95	66	0.50501	0.03707	737.31
26	16	2	95	66	0.6504	0.02619	441.97
27	11	3	95	66	0.70613	0.01888	328.42

Verification of ANOVA Assumptions:

MC Rate Estimate Factorial Model:

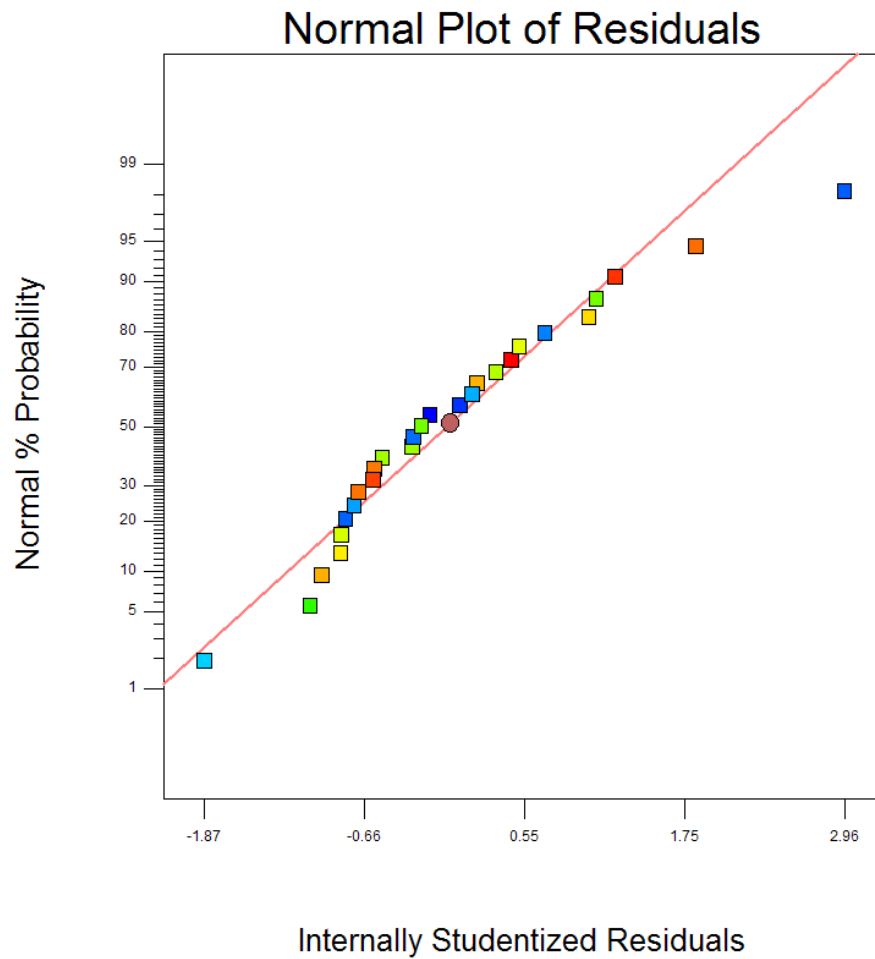


Figure 28. Normal Probability Plot of the Studentized Residuals for the MC Rate Estimate Factorial Model

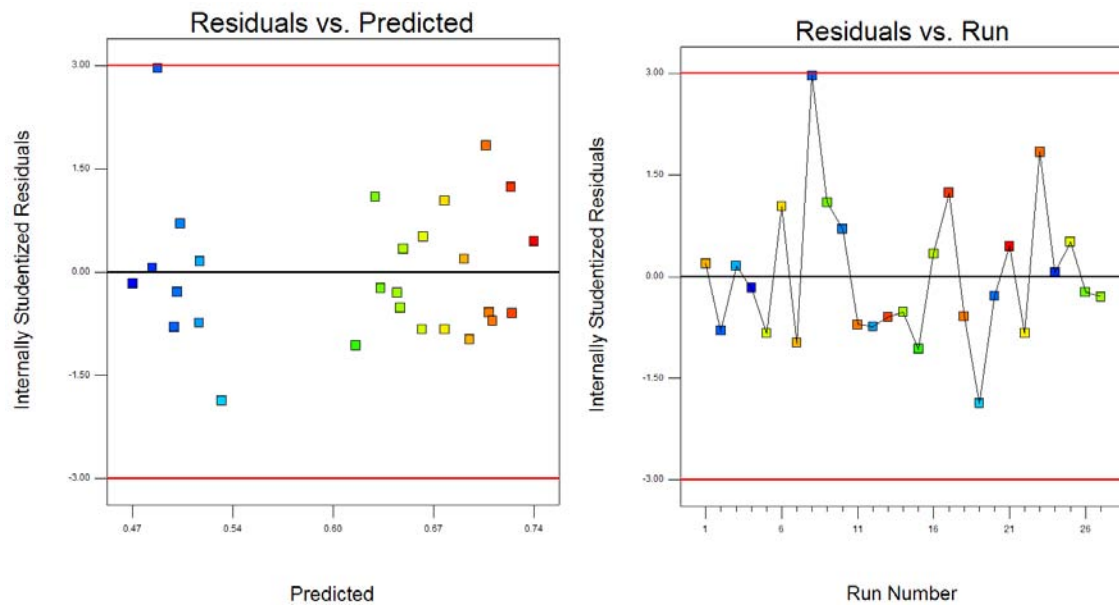


Figure 29. Studentized Residual Plots for the MC Rate Estimate Factorial Model

TNMCS Rate Factorial Model:

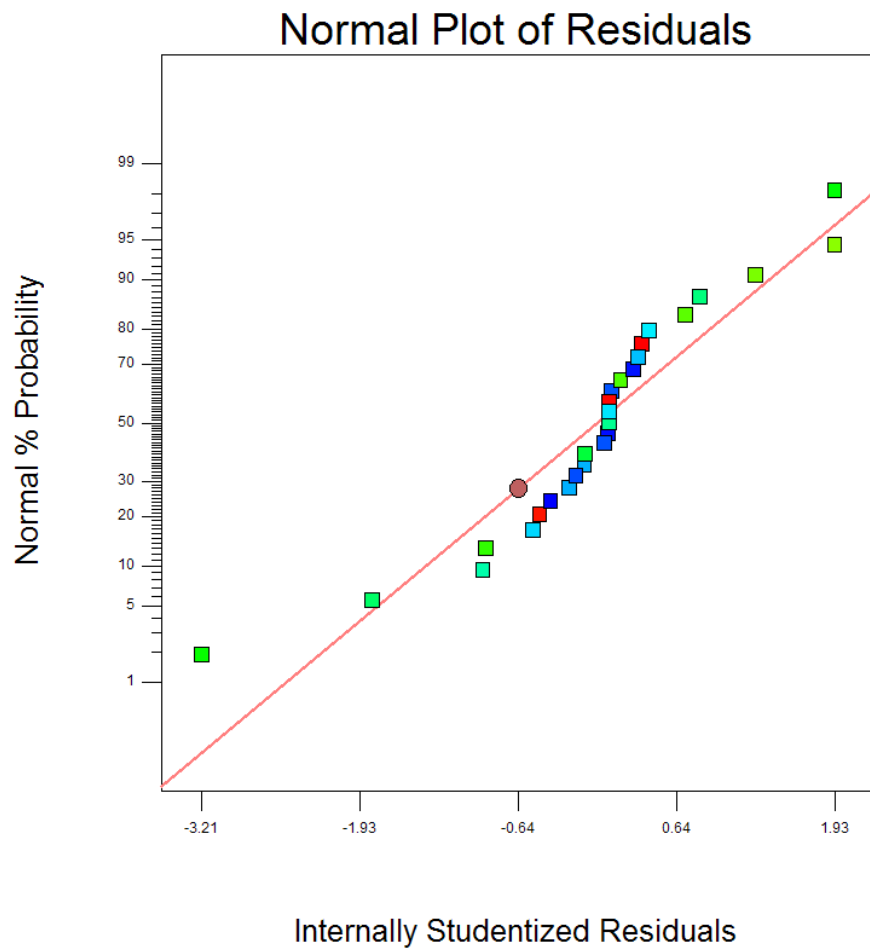


Figure 30. Normal Probability Plot of the Studentized Residuals for the TNMCS Rate Factorial Model

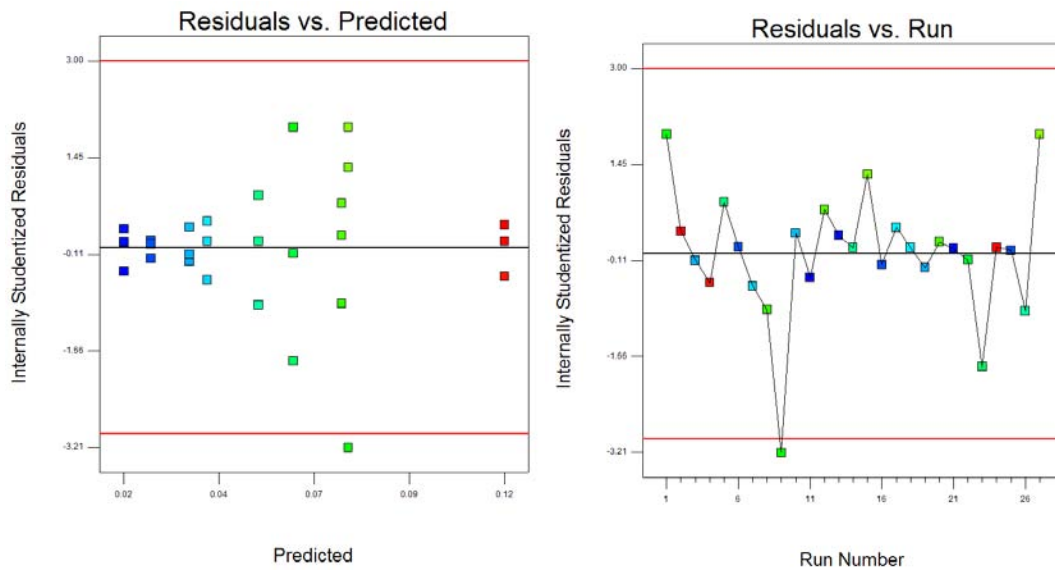


Figure 31. Studentized Residual Plots for the TNMCS Rate Factorial Model

Average Total Unscheduled Maintenance Days Factorial Model:

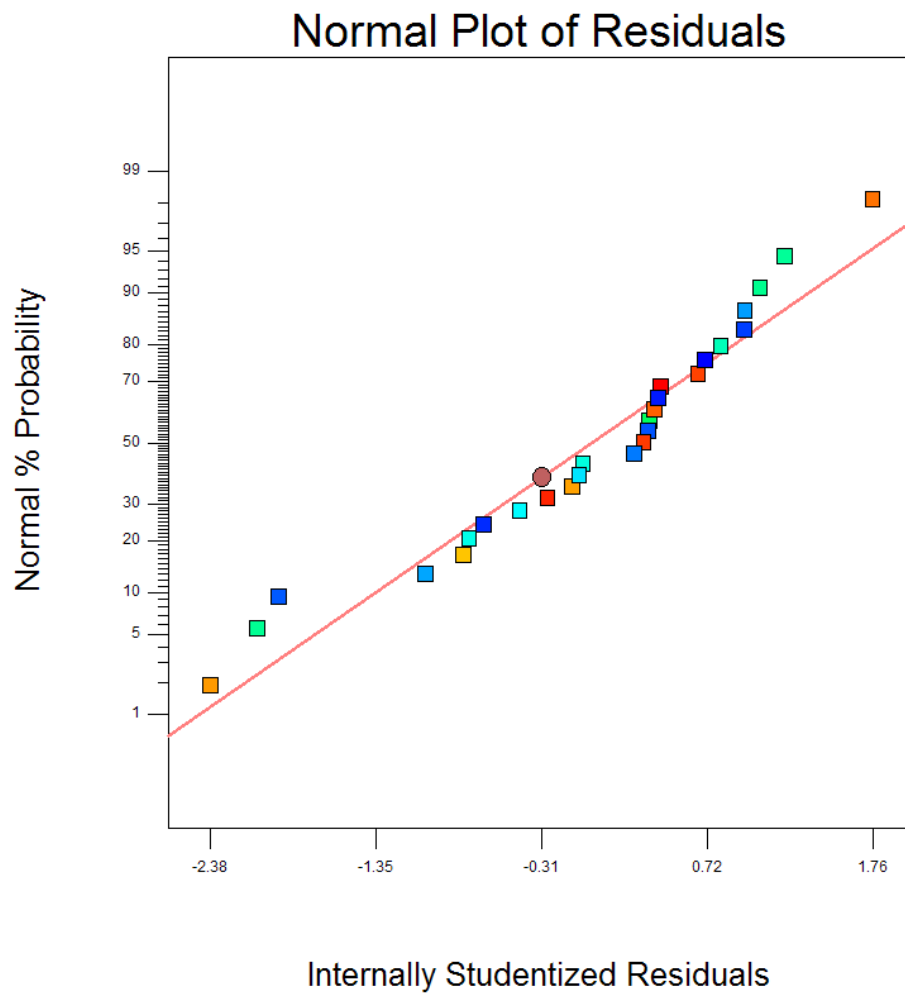


Figure 32. Normal Probability Plot of the Studentized Residuals for the Average Total Unscheduled Maintenance Days Factorial Model

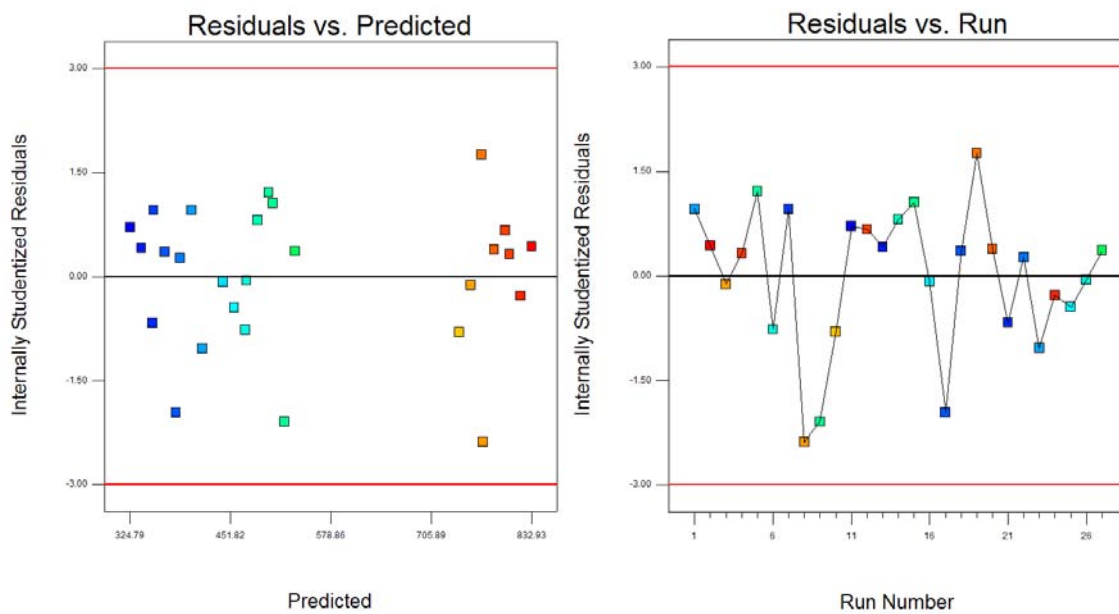


Figure 33. Studentized Residual Plots for the Average Total Unscheduled Maintenance Days Factorial Model

Note that for all three models, the normal probability plots of the residuals do not appear grossly nonnormal. Generally, for ANOVA, reasonable departures from normality are tolerable, since the F test is only slightly affected by skewed distributions (Montgomery, 2009). The residuals vs. run plots for all three models show proper randomization for obtaining independence. The residuals vs. predicted plots for all three models do reveal a problem of nonconstant variance among the residuals, which is especially noticeable in the TNMCS rate factorial model (Figure 31). However, violating the assumption of homogeneous variance among the residuals does not significantly affect the F tests used in the ANOVA if a balanced model is used (Montgomery, 2009).

Table 16. R^2 Values for the Factorial Models

	R-squared	Adjusted R-squared
MC Rate Estimate	0.99917	0.998921008
TNMCS Rate	0.9923911	0.989009343
Average Total UM Days	0.999174	0.998926254

Appendix E. Blue Dart

Improving B-1B Availability with High Velocity Maintenance

Military aircraft, unlike fine wines, do not get better with age. During the Vietnam War, the average age of a US military aircraft was nine years. Currently, that average has ballooned to about 24 years, and planes such as the KC-135 Stratotanker are routinely flown by pilots roughly half as old as the aircraft itself (Montgomery, 2007). As the fleet has continued to age, aircraft failures have become more frequent, which has largely contributed to decreasing aircraft availability rates. The Rockwell B-1B Lancer is an airframe being hit particularly hard with failures and subsequent aircraft availability issues.

In an effort to improve B-1B availability rates, the USAF is in the process of implementing a new maintenance program that has been dubbed High Velocity Maintenance (HVM). The main feature of HVM is to rework the Programmed Depot Maintenance (PDM) cycle of the B-1B to reduce the current PDM flow days. Each aircraft is brought to the depot for PDM more frequently, but for much briefer periods of time. HVM also provides depot mechanics more frequent contact with aircraft in the fleet, which is projected to improve aircraft failure rates. The idea is that with more frequent depot visits, mechanics will have a better idea of the effects of heavy usage on the fleet and can prepare for common repairs that will be required, to include kitting of parts to be repaired or replaced. This process could significantly speed up depot maintenance task time and increase the time between aircraft failures.

The objective of this research was to determine the impact that HVM would have on B-1B aircraft availability rates and other fleet performance metrics by examining the proposed changes to the field maintenance processes for the two B-1B squadrons of the 28th Bombardment Wing at Ellsworth AFB, SD. A comparison of the discrete-event simulation models developed through this research revealed that the reduced PDM flow days alone would not bring B-1B availability rates anywhere close to acceptable levels. In fact, due to the abundance of aircraft failures affecting the B-1B fleet, the modified PDM schedule introduced with HVM will have no noticeable impact on aircraft availability if failure rates do not improve. The main factor driving the B-1B availability rates are not the delays experienced at the depot during PDM, but the aircraft failures requiring unscheduled maintenance.

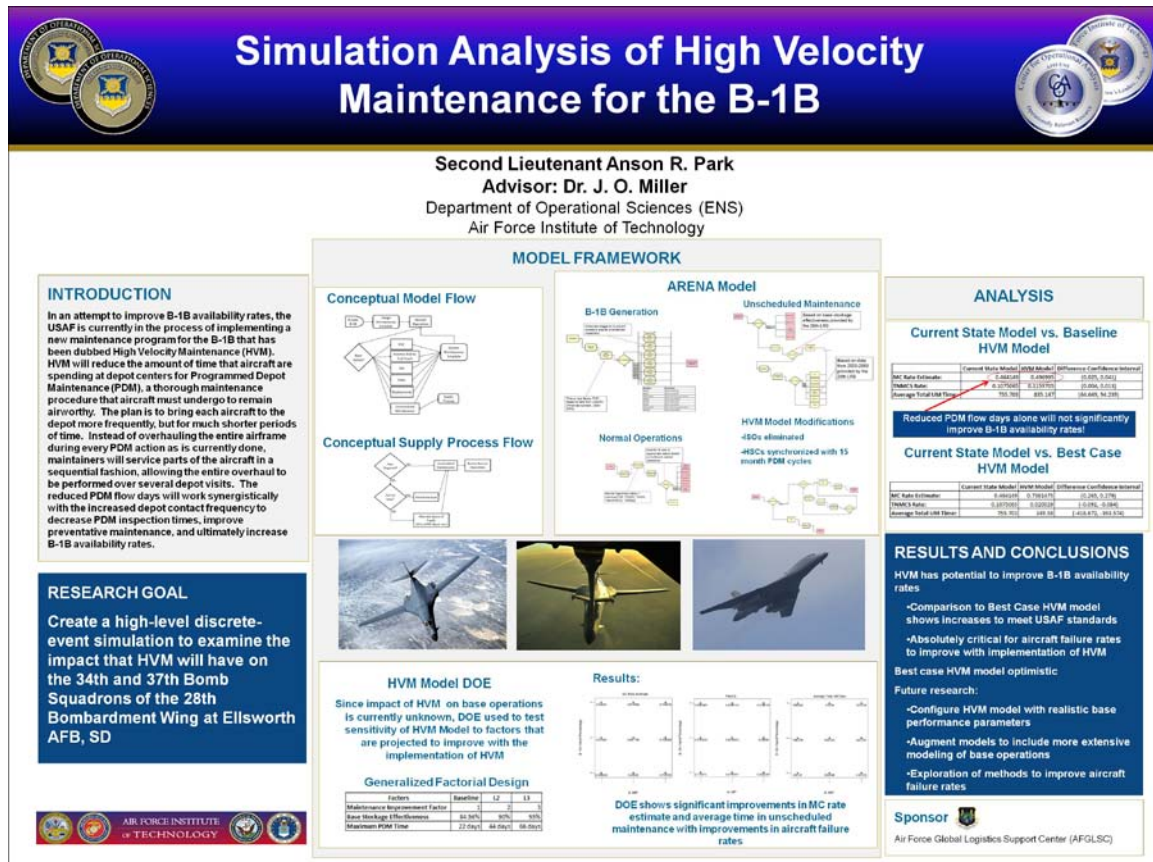
Those responsible for the implementation of HVM must look beyond the projected increase in depot maintenance tasks completed each depot visit and examine ways to improve B-1B failure rates to significantly impact availability. This can be accomplished by focusing on several aspects of unscheduled maintenance:

- 1) Reducing the amount of failures experienced. The opportunity for depot mechanics to touch each airframe more frequently, in addition to the synchronization of field and depot maintenance actions under HVM, needs to be used effectively to create better preventative maintenance for each B-1B.
- 2) Reducing the time each aircraft spends undergoing unscheduled maintenance when a failure occurs. The HVM pilot team should be examining ways to

expedite unscheduled field maintenance for the B-1B, to include kitting of commonly needed parts at the base level.

The success of HVM for the B-1B could have dramatic implications for the rest of the Air Force inventory. Finding a way to effectively maintain an aging fleet is critical in ensuring air and space dominance for the foreseeable future.

Appendix F. ENS Quad Chart



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Vita

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